A Novel Apporach to Design an Inset Feed Microstrip Patch Antenna using FR-4 (Lossy) Substrate

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Abstract— In the recent scenario there is a large demand to design a multiband microstrip patch antenna which can be used for multiple applications. In order to design a multiband microstrip patch antenna at first the designer must have to select the suitable substrate material. Proper selection of substrate is an important task for designing a multiband microstrip patch antenna. This paper represents design of an inset feed multiband microstrip patch antenna. The performance parameters like return loss, VSWR and others are evaluated using CST microwave studio. The frequency selected for designing of multiband inset feed rectangular microstrip patch antenna is 2.4GHz and the substrate selected for designing patch antenna is FR-4 (lossy) which has dielectric constant $\varepsilon_r = 4.3$.

Keywords: Inset Feed, Dielectric Constant, Bandwidth, Return Loss, Gain, Directivity, Radiation Efficiency

I. INTRODUCTION

The idea of patch antenna was originated in the early 1950s, but there was less activity for almost two decades due to its inherent narrow bandwidth. The patch antenna began to attract the serious attention to the antenna designers in the 1970s, as antenna designers began to appreciate the advantages offered by this type of antennas, which include low profile, conformability to a shaped surface, ease of fabrication, and compatibility with integrated circuit technology. In the last three decades, extensive studies have been devoted to improving the bandwidth and other performance characteristics.

The basic geometry of a microstrip patch antenna (MPA) consists of a metallic patch which is printed on one side and a ground plane which is printed on another side of substrate. In order to simplify analysis and performance prediction, the patch is generally can have square, rectangular, circular, triangular, and elliptical or some other common shape. The antenna is usually fed either by a stripline or a coaxial probe. In the coaxial feed patch antenna, the centre conductor is directly connected to the patch and the outer conductor to the ground. In the stripline feed patch antenna, energy is coupled to the patch in several ways: by proximity coupling, by direct connection and by aperture coupling.

For a rectangular microstrip patch antenna, the length L of the patch is usually $0.3333\ \lambda_0 < L < 0.5\ \lambda_0$, where λ_0 is the wavelength in free-space. 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 choosing in the rage $0.003\ \lambda_0 \leq h \leq 0.05\ \lambda_0$.

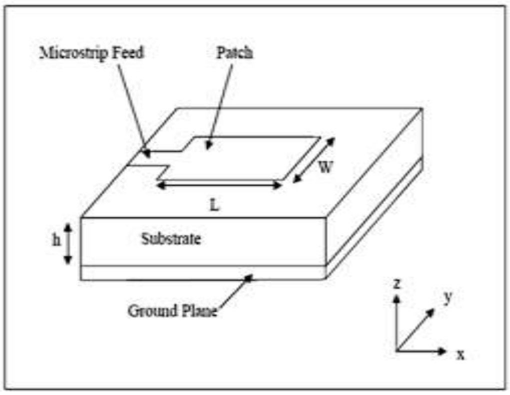

Fig. 1: Microstrip patch antenna

The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \leq \varepsilon_r \leq 12$. Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane.

For designing a multiband microstrip patch antenna which is having good performance, selection of proper dielectric substrate and notch gap are desirable since this provide better efficiency, larger bandwidth and better radiation. In order to design a compact multiband microstrip patch antenna a trade-off must be realized to select proper notch gap to get best performance of antenna.

II. DESIGN PROCEDURE & SIMULATION OF DESIGNED ANTENNA

The various steps involved for designing procedure of a microstrip patch antenna with inset feed in microwave CST studio suite is mentioned below.

1) Calculation of the dimension of the patch antenna, substrate, ground plane, effective dielectric constant, input impedance etc.
2) By using these parameter, we start for designing a patch antenna in CST microwave studio suite firstly we are drawing a substrate after that ground plane, patch antenna, gap between the patch and microstrip feed and feedline.
3) The last step involves simulation and optimization of patch antenna.

The picture of an inset feed patch antenna is shown below: -

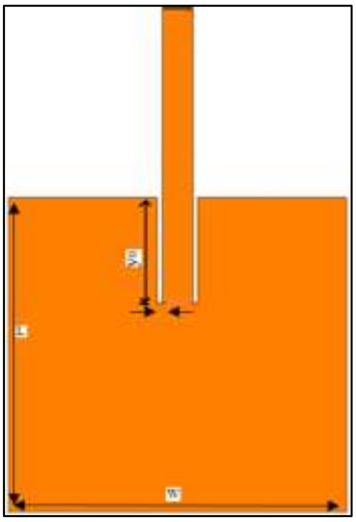

Fig. 2: Dimensions of an inset feed microstrip patch antenna

STEP A: Calculations of the dimensions of the patch antenna

STEP 1: Calculation of the Width of the patch (W)

$$Width = \frac{c}{2f_o\sqrt{\frac{\varepsilon_r+1}{2}}}$$

STEP 2: Calculation of Effective dielectric constant (ε_{reff}):

$$\varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right]$$

STEP 3: Calculation of the extended length (ΔL)

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

STEP 4: Effective length (L_{eff})

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

STEP 5: Calculation of the actual length of the patch (L)

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

STEP 6: Determination of Inset feed depth (y_0)

Let the input impedance of the feed line is 50 ohms for the specified resonant frequency. Hence, a trial and error method is used to locate the feed point inside the patch of an antenna. To obtain the optimum feed depth, where the return loss (R.L) is most negative (i.e. the least value). According to there exists a point along the length of the patch which gives the minimum return loss.

$$R_{in}(y=y_0) = \frac{1}{2(G_1 \pm G_{12})}\cos^2\left(\frac{\pi}{L}y_0\right) = R_{in}(y=0)\cos^2\left(\frac{\pi}{L}y_0\right)$$

Where,

$$R_{in}(y=0) = \frac{1}{2(G_1 \pm G_{12})}$$

$$Z_c = \begin{cases} \dfrac{60}{\sqrt{\epsilon_{reff}}}\ln\left[\dfrac{8h}{W_0}+\dfrac{W_0}{4h}\right], & \dfrac{W_0}{h} \le 1 \\ \dfrac{120\pi}{\sqrt{\epsilon_{reff}}\left[\dfrac{W_0}{h}+1.393+0.667\ln\left(\dfrac{W_0}{h}+1.444\right)\right]}, & \dfrac{W_0}{h} > 1 \end{cases}$$

Where,

$$G_1 = \begin{cases} \dfrac{1}{90}\left(\dfrac{W}{\lambda_0}\right)^2 & W \ll \lambda_0 \\ \dfrac{1}{120}\left(\dfrac{W}{\lambda_0}\right) & W \gg \lambda_0 \end{cases}$$

And

$$G_{12} = \frac{1}{120\pi^2}\int_0^{\pi}\left[\frac{\sin\left(\frac{k_0W}{2}\cos\theta\right)}{\cos\theta}\right]^2 J_0(k_0L\sin\theta)\sin^3\theta\, d\theta$$

Using the above equations while assuming that Z_C is equal to 50 Ω i.e. Rin (y=y0) = 50 Ω.

STEP 7: Calculation of the width of the feedline (W_f)

$$Z_c = \frac{120\pi}{\sqrt{\epsilon_{reff}}\left[\frac{W_f}{h}+1.393+0.667\ln\left(\frac{W_f}{h}+1.444\right)\right]}$$

Parameters	Material FR-4 (lossy)
Dielectric constant (ε_r)	4.3
Width of patch (W_p)	38.3934 mm
Length of patch (L_p)	29.7786 mm
Length of feedline (L_f)	15.0597 mm
Inset feed point distance (Y_0)	11.0192 mm
Width of feedline (Wf)	3.3137 mm
Substrate thickness (h)	1.5 mm
Thickness of material (Mt)	0.12491 mm

Table 1: Dimentions of patch antenna

III. SIMULATION RESULTS

The antenna was modeled and simulated using CST microwave studio. Designed inset feed patch antenna have an inset depth of 11.0192 mm, feed-line width of 3.3137 mm and feed length of 15.0597 mm. The designed antenna was found to be resonant at frequencies 2.3604 GHz.

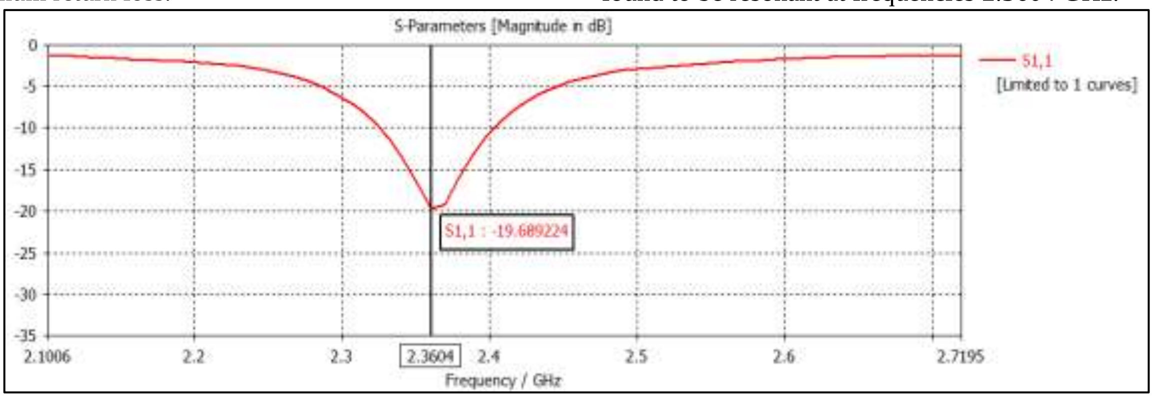

Fig. 3: Return loss of the designed microstrip patch antenna

The center frequency is chosen as the one at which the return loss is least. The bandwidth can be figured from the return loss (RL) plot. The bandwidth of the antenna can be said to be those scope of frequencies over which the RL is more than -9.5 dB (-9.5 dB relates to a VSWR of 2 which is the acceptable figure).

The designed patch antenna is having maximum value of return loss -19.689224 dB at frequency 2.3604 GHz. The bandwidth of the designed antenna for this feed point location has been calculated as shown below in Figure 4. In this design the inset feed microstrip patch antenna having fc1=2.3238 GHz and fc2=2.4062 GHz therefore the designed antenna having the bandwidth 0.08238 GHz at the center frequency of 2.3604 GHz. The result which is obtained is very close to the desired design frequency 2.4 GHz of an inset feed microstrip patch antenna.

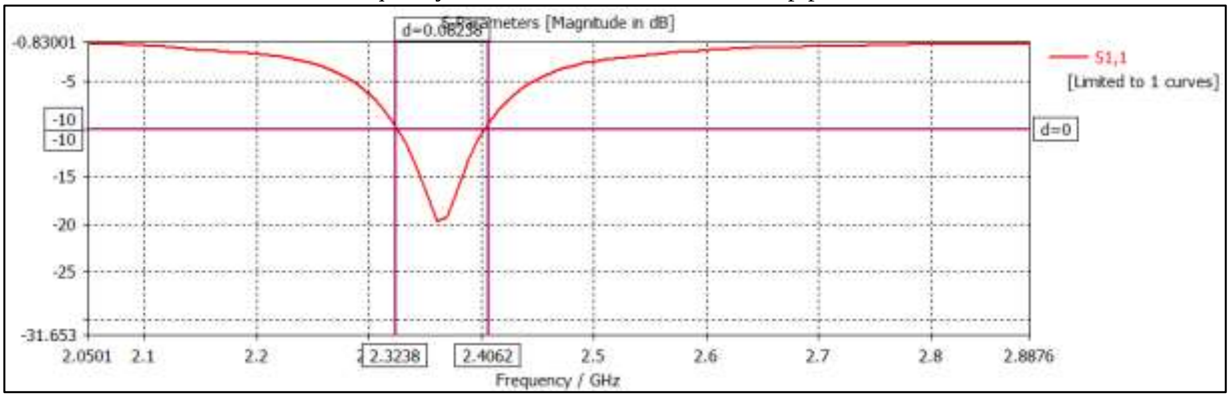

Fig. 4: Bandwidth of designed microstrip patch antenna

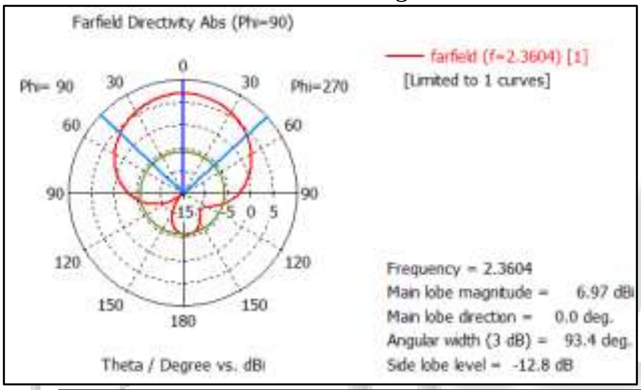

Fig. 5: Elevation pattern for φ = 90 degrees

Ideally, VSWR must lie in the range of 1-2 which is achieved in figure 6 for the frequency 2.3604 GHz, near the operating frequency value.

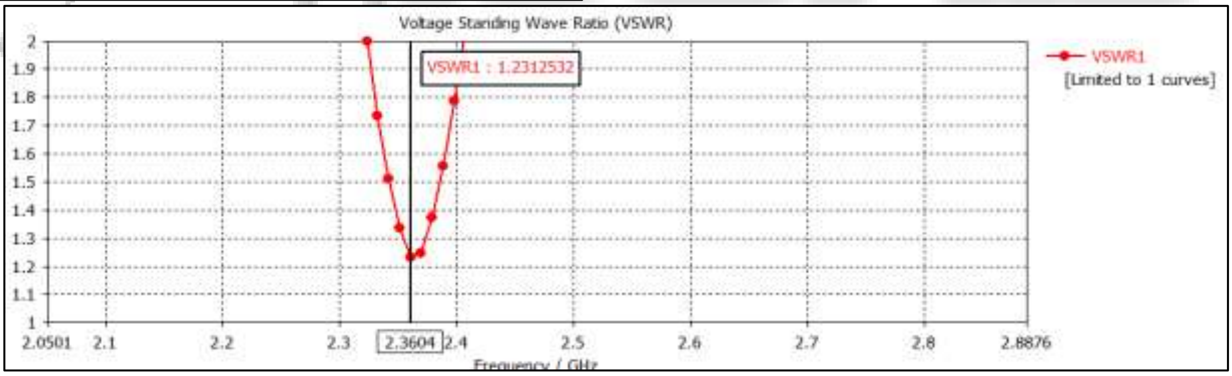

Fig. 6: VSWR of designed microstrip patch antenna

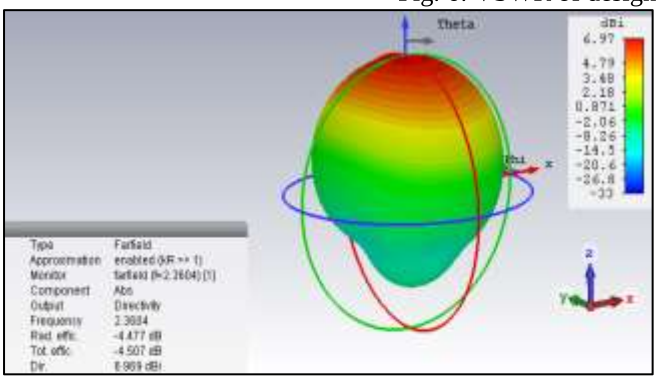

Fig. 7: 3D radiation pattern of designed antenna

IV. Conclusion

The work in this paper was focused on the design of an inset feed microstrip patch antenna using FR4 (lossy) substrate which can operate at the center frequency 2.4 GHz. The proposed patch antenna is having maximum value of return loss -19.689224 dB at frequency 2.3604 GHz which is much closer to the selected center frequency. The designed patch antenna having gain 6.97 dBi and directivity 6.969 dB. The proposed antennas have achieved good impedance matching, stable radiation patterns, and high gain at frequency 2.3604 GHz.

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