Designing & Testing of an Inset Fed Microstrip Patch Antenna Operating at 2.24 GHz using CST

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Abstract— This paper describes the design and fabrication technique of an inset fed rectangular microstrip patch antenna operating at 2.24GHz. All the designs have the substrate having dielectric constant (εr) 4.3, substrate thickness of 1.524 mm and loss tangent of 0.025. This paper is mostly focused on the designing of an inset fed patch antenna which has been carried out by using CST studio suite. The aim of this paper is on the measurement of return loss, VSWR and bandwidth of designed patch antenna.

Keywords: Microstrip Patch Antenna, CST, inset feed microstrip patch antenna

I. INTRODUCTION

An antenna is the basic element which employed for radiating or receiving electromagnetic wave. Although antennas may seem to be available in numerous different shapes and sizes, they all function according to the same basic principles of electromagnetic. There are many types of portable electronic devices, such as cellular phones, GPS receivers, palm electronic devices, pagers, laptop computers, and telemetric unit in vehicles, need an effective and efficient antenna for communicating wirelessly with other fixed or mobile communication units. Advancement in digital and radio electronics have results its output in the production of a new breed of personal communications equipment posing special problems for antenna designers. Personal wireless communication devices have created an enhanced demand for compact antennas. The increase in satellite communication has also enhanced the demand for antennas that are compact and supplies reliable transmission. In addition, the enlargement of wireless local area networks at home and work has also necessitated the requirement for antennas that are compact and cheap.

Today microstrip patch antenna are preferred over the other antennas because they are better compatibility is to be fit in Mobile, Aircraft, Satellites owing to very small sizes than the other commercial antenna which are available in present world scenario[4]. Hence design and development of superior and cost effective microstrip patch antenna has become an attractive research area.

The most fundamental form of 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 or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric 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. 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 $t << \lambda_0$ (where t is the thickness of patch). The height h of the dielectric substrate is usually chooses in the rage $0.003\ \lambda_0 \le h \le 0.05\ \lambda_0$.

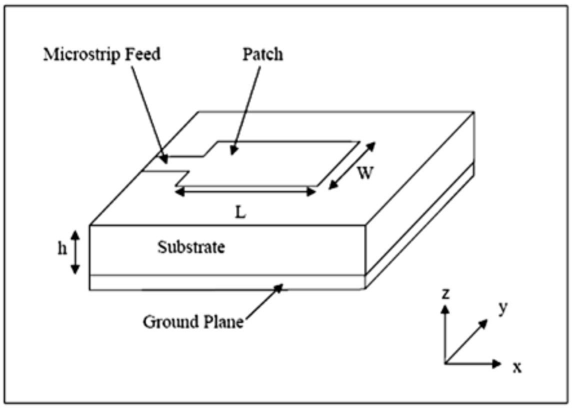

Fig. 1: Microstrip patch antenna

The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \le \varepsilon_r \le 12$. Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation. However, such a configuration leads to a larger antenna size. In order to design a compact microstrip patch antenna, substrates with higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a trade-off must be realized between the antenna dimensions and antenna performance.

In this paper the simplest method of feeding the patch i.e. the transmission line model has been used.

II. TRANSMISSION LINE MODEL

This model represents the microstrip antenna by two slots of width W and height h, separated by a transmission line of length L [2].The microstrip is essentially a non-homogeneous line of two dielectrics, typically the substrate and air.

Hence, as seen from Figure 3, most of the electric field lines reside in the substrate and parts of some lines in air. As a result, this transmission line cannot support pure transverse-electromagnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant (εeff) must be obtained in order to account for the fringing and the wave propagation in the line. The value of εeff is slightly less than εr because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air. The expression for εreff is given by Balanis [2] as:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{-1/2}$$

Where, ε_{reff} = effective dielectric constant,

ε_r = dielectric constant of substrate

h = height of dielectric substrate

W = width of the patch

In order to operate in the fundamental TM10 mode, the length of the patch must be slightly less than $\lambda/2$ where λ is the wavelength in the dielectric medium and is equal to $\lambda_0/\sqrt{\varepsilon reff}$ where λ_0 is the free space wavelength. The TM10 mode implies that the field varies one $\lambda/2$ cycle along the length, and there is no variation along the width of the patch.

In the Figure 2 shown below, the microstrip patch antenna is represented by two slots, separated by a transmission line of length L and open circuited at both the ends. Along the width of the patch, the voltage is maximum and current is minimum due to the open ends. The fields at the edges can be resolved into normal and tangential components with respect to the ground plane [2].

It is seen from Figure 3 that the normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase since the patch is $\lambda/2$ long and hence they cancel each other in the broadside direction. The tangential components which are in phase, means that the resulting fields combine to give maximum radiated field normal to the surface of the structure

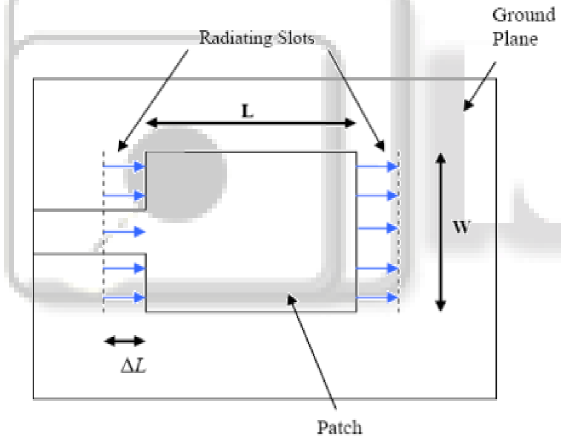

Fig. 2: Top view of microstrip patch antenna

Hence the edges along the width can be represented as two radiating slots, which are $\lambda/2$ apart and excited in phase and radiating in the half space above the ground plane.

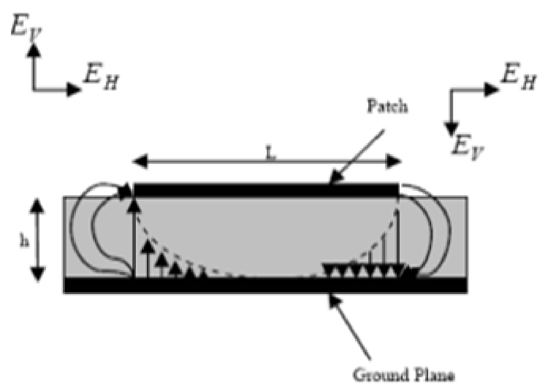

Fig. 3: Bottom view of microstrip patch antenna

The fringing fields along the width can be modeled as radiating slots and electrically the patch of the microstrip antenna looks greater than its physical dimensions. The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is given empirically by

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

Where

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{-1/2}$$

The effective length of the patch Leff now becomes

$$L_{eff} = L + 2\,\Delta L$$

For a given resonance frequency f_r, the effective length Leff is given by:

$$\text{Leff} = \frac{c}{2fr\sqrt{\epsilon_{eff}}}$$

For a rectangular microstrip patch antenna, the resonance frequency for any TM_{mn} is given as

$$f_o = \frac{c}{2\sqrt{\epsilon_{eff}}}\quad\left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2\right]^{1/2}$$

Where m and n are modes along L and W respectively. For efficient radiation, the width W is given as

$$W = \frac{1}{2fr\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_{reff}+1}} = \frac{c}{2fr}\sqrt{\frac{2}{\epsilon_{reff}+1}}$$

Where C is the free space velocity of light

III. 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.

- Calculation of the dimension of the patch antenna, substrate, ground plane, effective dielectric constant, input impedance etc.
- By using these parameter we starts 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.
- The last step involves simulation and optimization of patch antenna.

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

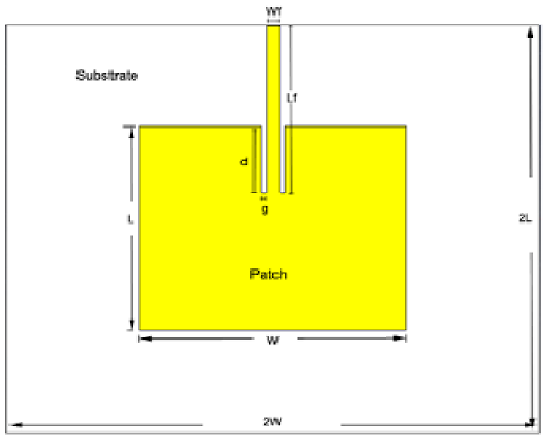

Fig. 4: Dimensions of an inset feed microstrip patch antenna

A. *STEP A:*

Calculations of the dimensions of the patch antenna

Step 1: Calculation of the Width of the patch **(W):** The width of the Microstrip patch antenna is given as:

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

Width = 41.1358 mm

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

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

ε_{reff} = 4.0228

Step 3: Calculation of the extended length ΔL

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

ΔL = 0.70705 mm

Step 4: Effective length (L_{eff})

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

L_{eff} = 33.387 mm

Step 5: Calculation of the actual length of the patch L: Since the length of the patch has been extended by ΔL on each side, the effective length of the patch is now (L = λ/2 for dominant TM10 mode with no fringing). The effective length is given by:

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

L = 31.9729 mm

Step 6: Determination of Inset feed depth (y_0): An inset fed type feeding is to be used in this design. An inset feed point is the point located inside the patch of an antenna where the impedance of the feed microstrip and the patch antenna is matched or become equal and thus least amount of energy is reflected back to the microstrip and most of the energy is radiated from the antenna. As shown in Figure 5, the feed depth is given by y_0.

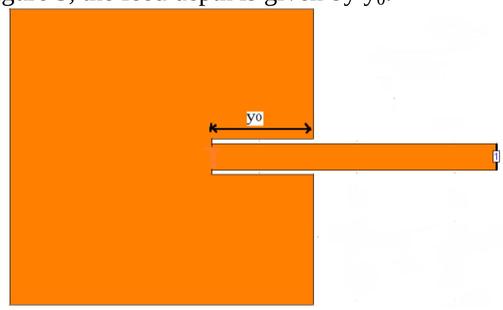

Fig 5: An inset feed microstrip patch antenna

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 [3] 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,

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

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

Where,

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

And

$$G_{12} = \frac{1}{120\pi^2}\int_0^{\pi}\left[\frac{\sin\left(\frac{k_0 W}{2}\cos\theta\right)}{\cos\theta}\right]^2 J_0(k_0 L \sin\theta)\sin^3\theta \, d\theta$$

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

y_0 = 11.8333 mm

Step 7: Calculation of the length and width of the feedline (L_f and W_f): Now we have to calculate the length and width of feedline with impedance of 50 ohms. The width of microstrip line can be finding by using formula;

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

W_f = 2.9665 mm and L_f = 27.81975 mm

Step 8: Calculation of the ground plane dimensions (Lg and Wg): The transmission line model is relevant to infinite ground planes only. However, for practical considerations, it is necessary to have a finite ground plane. It has been shown by [1] that 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. Hence, calculation for the ground plane dimensions would be given as:

Lg = 6h + L = 41.1169 mm

Wg = 6h + W = 50.2798mm

B. *STEP B & C:*

Design & simulation setup of microstrip patch antenna and its result in CST microwave studio

The software used to model and simulate the Microstrip patch antenna is CST studio suite. CST studio suite is a full-wave electromagnetic simulator based on the method of moments. It analyzes 3D and multilayer structures of general shapes. It has been widely used in the design of MICs, RFICs, patch antennas, wire antennas, and other RF/wireless antennas. It can be used to calculate and plot the S11 parameters, VSWR, current distributions as well as the radiation patterns.

The inset feed used is designed to have an inset depth of 11.8333mm, feed-line width of 2.9665 mm and feed path length of 27.81975mm. A frequency range of 2.2-3.5 GHz is selected and 2.1836 GHz frequency points are selected over this range to obtain accurate results.

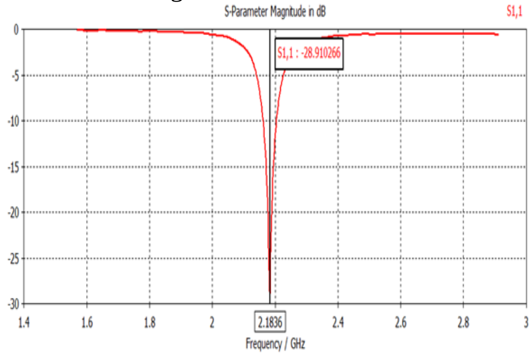

Fig. 6: Return loss of the designed microstrip patch antenna

The center frequency is selected as the one at which the return loss is minimum. The bandwidth can be calculated from the return loss (RL) plot. The bandwidth of the antenna can be said to be those range of frequencies over which the RL is greater than -9.5 dB (-9.5 dB corresponds to a VSWR of 2 which is an acceptable figure). Using the optimum feed depth is found to be at y_0 = 11.8333mm where a RL of -28.910266 dB is obtained.

The bandwidth of the antenna for this feed point location has been calculated as shown below in Figure 7. In this design the inset feed microstrip patch antenna having fc1=2.2061 and fc2=2.1622 therefore the designed antenna having the bandwidth 439.08 MHz at the center frequency of 2.1836 GHz. The result which is obtained is very close to the desired design frequency 2.24 GHz of an inset feed microstrip patch antenna.

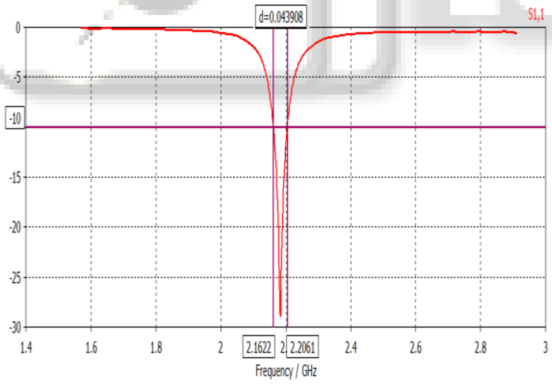

Fig. 7: Bandwidth of designed microstrip patch antenna

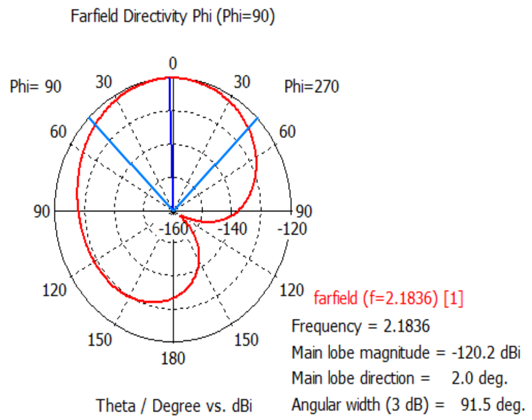

Fig. 8: Elevation pattern for φ = 90 degrees

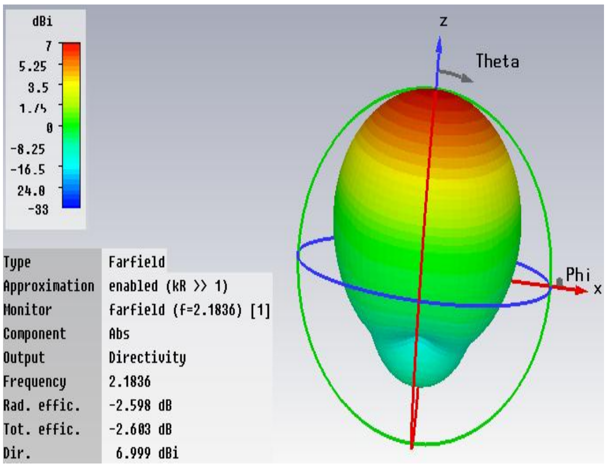

Fig. 9: 3 D radiation pattern of designed antenna

Ideally, VSWR must lie in the range of 1-2 which is achieved in figure 10 for the frequency 2.186 GHz, near the operating frequency value.

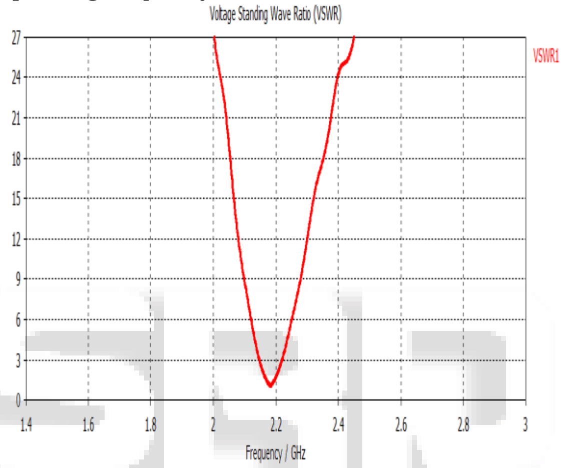

Fig. 10: VSWR of designed microstrip patch antenna

The 3D surface current distribution plot establishes the relationship between the co-polarization (desired) and cross-polarization (undesired) components. Moreover it gives a clear image as to the nature of polarization of the fields propagating through the patch antenna. Figure 11 clearly shows that the patch antenna is linearly polarized.

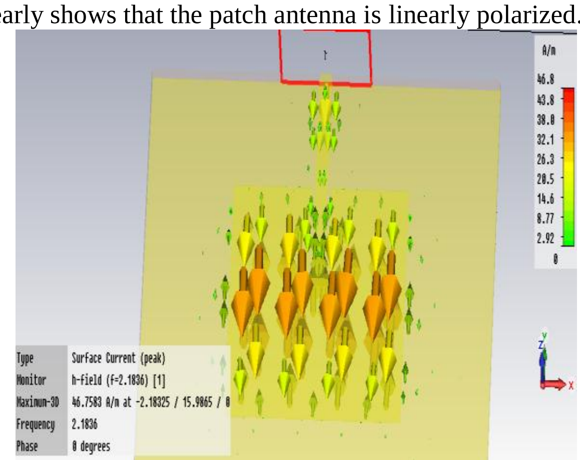

Fig. 11: Surface current of designed microstrip patch antenna

IV. Conclusion

The work in this thesis focused on the design of an inset feed microstrip patch antenna operated at the centre frequency 2.24 GHz. The proposed patch antenna is having maximum value of return loss at frequency 2.186 GHz which is much closer to the selected centre frequency. The proposed antennas have achieved good impedance matching, stable radiation patterns, and high gain at frequency 2.186 GHz. The designed inset feed microstrip patch antenna having bandwidth of 439 MHz's

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