A Novel Approach to Design a Multiband Inset Fed Microstrip Patch Antenna Using Rogers Substrate

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Abstract— This paper describes the design and fabrication technique of an inset fed rectangular microstrip patch antenna operating at 2.4 GHz. For designing of patch antenna rogers RT 5880 substrate is used which is having dielectric constant (εr = 2.2) and the substrate thickness equal to 1.5 mm. In this paper my work is mostly focused on the designing of a multiband inset fed patch antenna. The software used to carry out my work is CST studio suite. The aim of this paper is to design a microstrip patch antenna using rogers RT 5880 substrate and analyze it using the measurement of return loss, VSWR and bandwidth of designed patch antenna.

Keywords: Microstrip Patch Antenna, Rogers Substrate

I. INTRODUCTION

An antenna is a fundamental component which utilized for transmitting or accepting electromagnetic wave. Although antenna may appear to be accessible in various shape and size they all function as per a similar essential standards of electromagnetics. There are numerous sorts of convenient electronic gadgets for example phones, smart phones, laptops, GPS receivers, telemetric unit in vehicle need a successful and proficient antenna for discussing remotely with another fixed or portable correspondence units. The advancement in digital and radio hardware have results its yield in the generation of another type of personal communication equipment's presenting extraordinary issues for antenna designers. Personal wireless gadgets have made an improved demand for designing of compact antennas. The expansion in satellite correspondence has likewise upgraded the interest for reception apparatuses those are compact and can supply reliable transmission. Moreover, the growth of (WLAN) wireless local area network at homes and works has additionally required the prerequisite for antennas that are cheap and compact. Today microstrip patch antennas are favored over different other type of antennas since they are having better compatibility to be fit in the mobile, aircraft, satellites attributable to extremely little sizes than the other types of commercial antennas those are accessible right now in present world scenario. [4] Hence design and improvement of cost effective and superior microstrip patch antenna has become attractive research zone for the antenna designers. The basic type of a microstrip patch antenna comprises of radiating patch on one side and a ground plane on the opposite side of the dielectric substrate as shown in Fig. 1. The patch is commonly made of conducting lossy material for example copper, gold etc. and can take any shape. The dielectric substrate is sandwiched in between radiating patch and the ground plane.

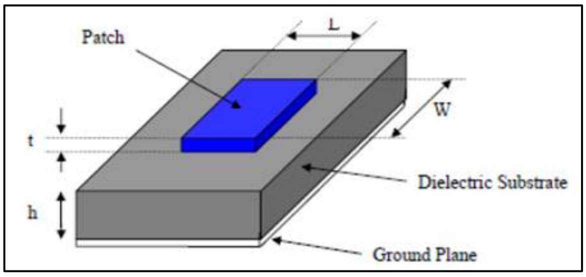

Fig. 1: Microstrip patch antenna

Where,

W = Width of the patch
L = Length of the patch
h = Height of dielectric substrate
t = Thickness of the substrate

Generally, in order to simplify, analyze and performance prediction, the radiating patch can have rectangular, square, triangular, circular and elliptical or any other common shapes. For designing a rectangular microstrip patch antenna, the patch must be selected to be very thin such that $t << \lambda_0$ (where t is the thickness of the patch) and the length L of the patch is usually selected in the range $0.3333\ \lambda_0 < L < 0.5\ \lambda_0$, where λ_0 is the wavelength in free-space. The height h of the dielectric substrate is usually selected in the rage $0.003\ \lambda_0 \leq h \leq 0.05\ \lambda_0$.

The dielectric constant of the substrate (ε_r) is selected in the range $2.2 \leq \varepsilon_r \leq 12$. Microstrip patch antennas radiate primarily because of the fringing fields between the patch and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since it provide 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 transmission line model for feeding the patch has been used to design a multiband microstrip patch antenna.

II. DESIGN MODELS FOR MICROSTRIP ANTENNAS

The most popular models for the design analysis of microstrip patch antennas are the transmission line model, cavity model, and full wave model. The transmission line model is the simplest of all and it gives good physical insight but it is less accurate. The cavity model on the other hand is more accurate and gives a better physical insight but is complex in nature. The full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling.

In this paper the transmission line model is used to design a rectangular microstrip antenna. Our design is simply based on the empirical equations governing the transmission line model. The basic parameters of the patch antenna are obtained from calculations carried out using the appropriate equations. Our main focus is to obtain data for different values of frequency of operation. The parameters of interest include the effective dielectric constant (ε_{reff}), patch width (W), patch length (L) and wavelength (λ). Analysis of the different scenarios is carried out using the plots generated from calculated results.

A. 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. The microstrip is essentially a non – homogenous line of two dielectrics, typically the substrate and air. As a result, this transmission line cannot support pure transverse electric magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. The value of effective dielectric constant (εreff) 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 ε_{reff} 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 TM_{10} mode, the length of the patch must be slightly less than λ/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 TM_{10} mode implies that the field varies one λ/2 cycle along the length, and there is no variation along the width of the patch.

In the Fig. 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 Fig. 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 λ/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.

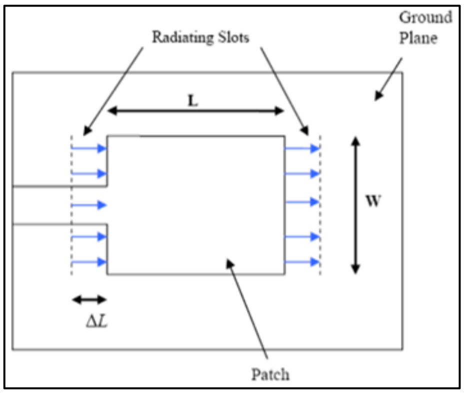

Fig. 2: Top view of microstrip patch antenna

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

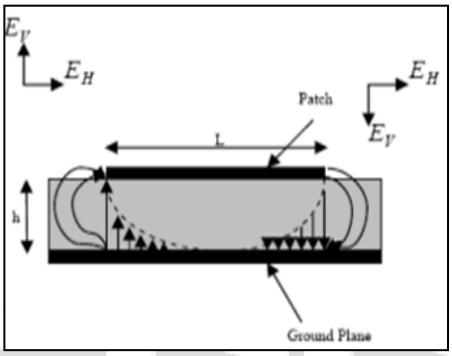

Fig. 3: Side view of microstrip patch antenna

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 L_{eff} now becomes

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

For a given resonance frequency f_r, the effective length L_{eff} is given by:

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

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

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

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

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

Where C is the free space velocity of light

III. DESIGN CALCULATIONS AND RESULTS

For designing the transmission line model of microstrip patch antenna using CST studio suite, the following calculation steps are used to determine the required parameters. As mentioned earlier, the calculations were carried out for various operating frequencies :

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: -

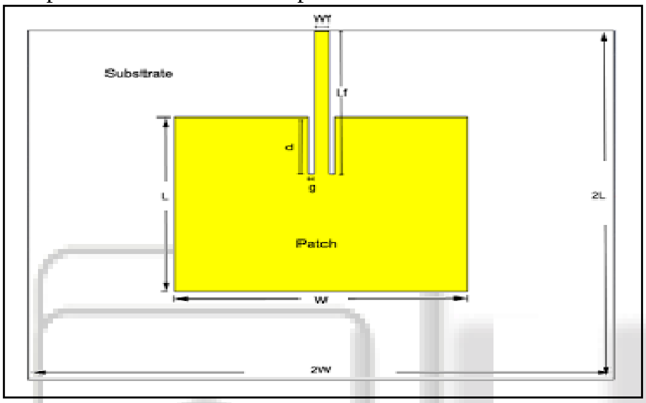

Fig. 4: Dimensions of an inset feed microstrip patch antenna

STEP A: Calculations of the dimensions of the patch antenna

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

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

Width = 49.4106 mm

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

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

$\varepsilon_{reff} = 2.1137$

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 = 0.79106 mm

STEP 4: Effective length (L_{eff})

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

L_{eff} = 42.9892 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 TM_{10} mode with no fringing). The effective length is given by:

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

L = 41.4071 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 Fig. 5, the feed depth is given by y_0.

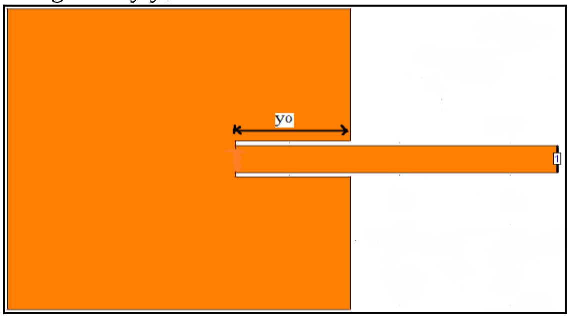

Fig. 5: An inset feed microstrip patch antenna

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 (RL) 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 = 14.5237 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;

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

$W_f = 4.6206$ mm and $L_f = 21.0542$ mm

STEP B & C: Design & simulation setup of microstrip patch antenna and its result in CST microwave studio

The software which has been 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 RFICs, MICs, wire antennas, patch antennas and other RF/wireless antennas. It can be used to calculate and plot the S_{11} parameters, VSWR, current distributions as well as the radiation patterns.

The designed inset feed patch antenna has an inset depth of 14.5237 mm, feed-line width of 4.6206 mm and feed line length of 21.0542 mm. The antenna is simulated over a range from 2 to 11 GHz and found to be resonant at frequencies 2.387 GHz, 4.026GHz, 4.576 GHz, 6.93 GHz and 9.416 GHz.

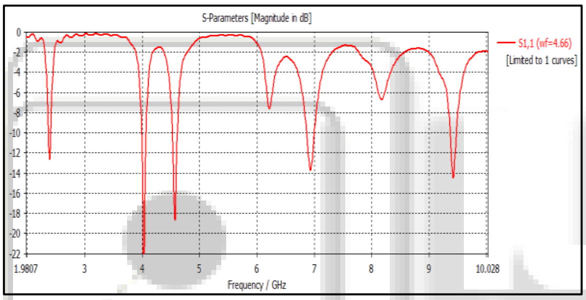

Fig. 6: Return loss of the designed microstrip patch antenna over a range from 2 to 11 GHz

The resonant 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 -10 dB. As we can see from Fig. 7 to Fig. 11 that at resonant frequencies 2.387 GHz, 4.026GHz, 4.576 GHz, 6.93 GHz and 9.416 GHz the return loss equal to -12.64, -22.13, -18.68, -13.73 and -14.49 respectively.

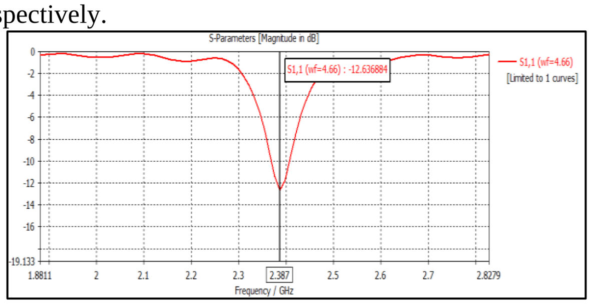

Fig. 7: Return loss of the designed microstrip patch antenna resonant at frequency 2.387 GHz

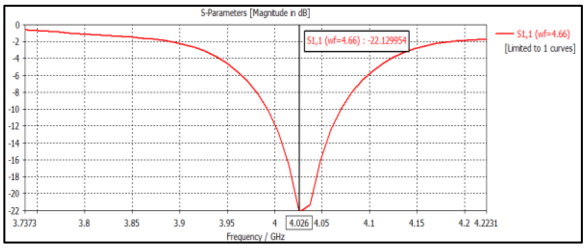

Fig. 8: Return loss of the designed microstrip patch antenna resonant at frequency 4.026 GHz

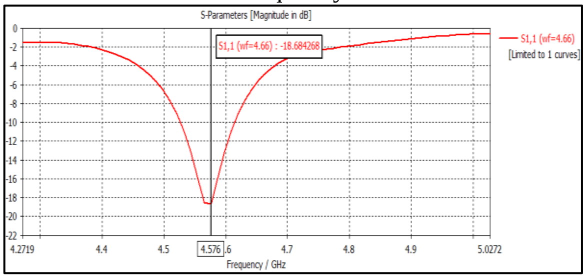

Fig. 9: Return loss of the designed microstrip patch antenna resonant at frequency 4.576 GHz

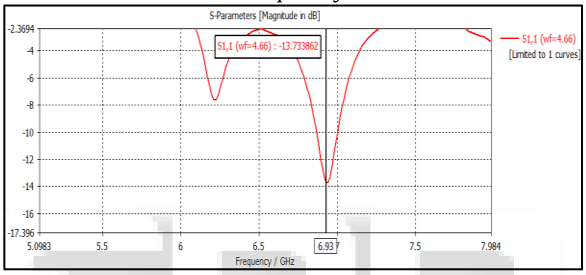

Fig. 10: Return loss of the designed microstrip patch antenna resonant at frequency 6.93 GHz

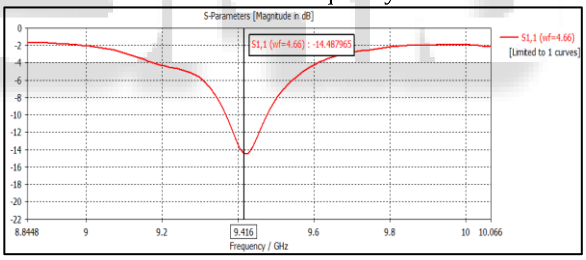

Fig. 11: Return loss of the designed microstrip patch antenna resonant at frequency 9.416 GHz

The bandwidth of the patch antenna for resonant frequency 2.387 having fc1=2.3663 GHz and fc2=2.4091 GHz therefore the designed antenna having the bandwidth 42.79 MHz as shown in Fig. 12. The result which is obtained is almost equal to the desired design frequency 2.4 GHz of an inset feed microstrip patch antenna.

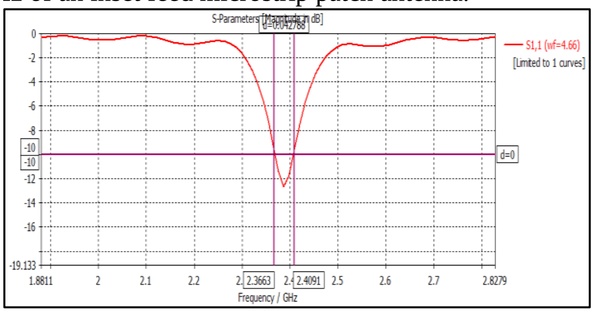

Fig. 12: Bandwidth of designed microstrip patch antenna for center frequency 2.387 GHz

The bandwidth of the patch antenna for resonant frequency 4.026 GHz having fc1=3.9922 GHz and fc2=4.0716 GHz therefore the designed antenna having the bandwidth 79.42 MHz as shown in Fig. 13.

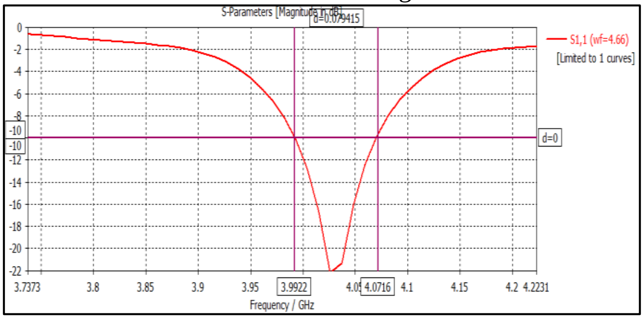

Fig. 13: Bandwidth of designed microstrip patch antenna for center frequency 4.026 GHz

The bandwidth of the patch antenna for resonant frequency 4.576 GHz having fc1=4.5259 GHz and fc2=4.6165 GHz therefore the designed antenna having the bandwidth 90.612 MHz as shown in Fig. 14.

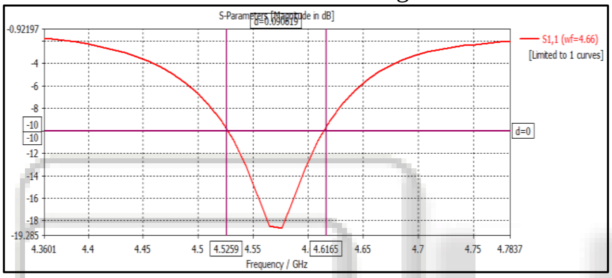

Fig. 14: Bandwidth of designed microstrip patch antenna for center frequency 4.576 GHz

The bandwidth of the patch antenna for resonant frequency 6.93 GHz having fc1=6.8675 GHz and fc2=7.0044 GHz therefore the designed antenna having the bandwidth 136.93 MHz as shown in Fig. 15.

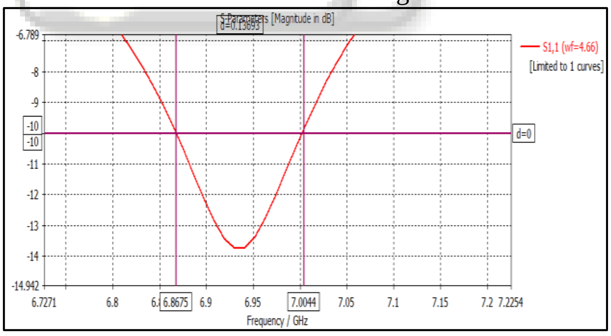

Fig. 15: Bandwidth of designed microstrip patch antenna for center frequency 6.93 GHz

The bandwidth of the patch antenna for resonant frequency 9.416 GHz having fc1=9.3678 GHz and fc2=9.4779 GHz therefore the designed antenna having the bandwidth 110.11 MHz as shown in Fig. 16.

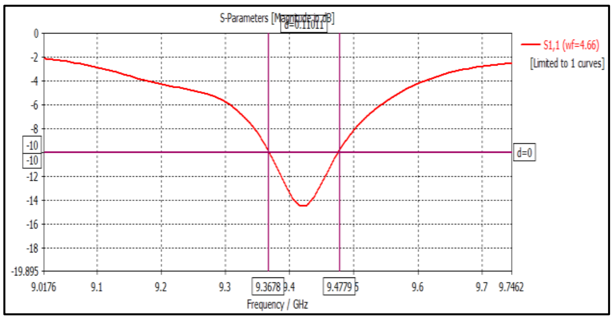

Fig. 16: Bandwidth of designed microstrip patch antenna for center frequency 9.416 GHz

The 3 D radiation pattern of designed antenna at resonant frequencies 2.387 GHz, 4.026GHz, 4.576 GHz, 6.93 GHz and 9.416 GHz shown in Fig. 17, Fig. 21 respectively. As we cab see that from Fig. 6 – to Fig. 7 that the designed patch antenna has directivity of 8.205 dBi, 7.686 dBi, 8.796 dBi, 11.77dBi and 10.43 dBi for resonant frequencies 2.387 GHz, 4.026GHz, 4.576 GHz, 6.93 GHz and 9.416 GHz respectively. The designed patch antenna at resonant frequencies 2.387 GHz, 4.026GHz, 4.576 GHz, 6.93 GHz and 9.416 GHz have directivity 8.205 dBi, 7.686 dBi, 8.796 dBi, 11.77 dBi and 10.43 dBi respectively as shown in Fig. 17 to Fig. 21.

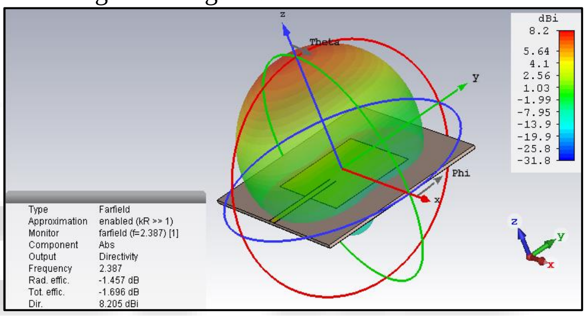

Fig. 17: 3 D radiation pattern of designed antenna at frequency 2.387 GHz

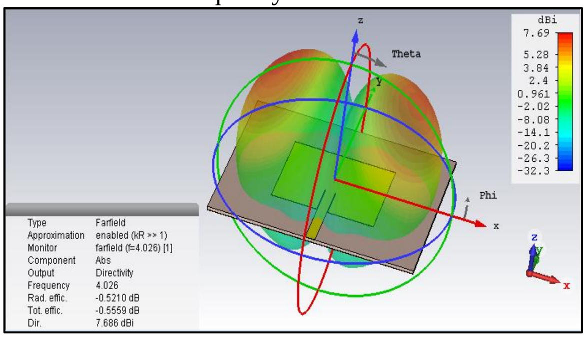

Fig. 18: 3 D radiation pattern of designed antenna at frequency 4.026 GHz

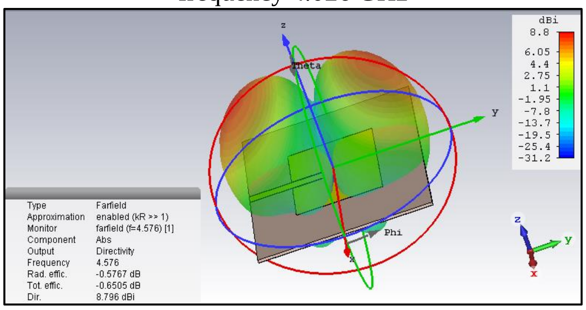

Fig. 19: 3 D radiation pattern of designed antenna at frequency 4.576 GHz

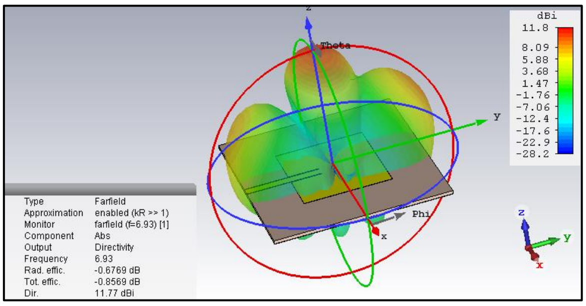

Fig. 20: 3 D radiation pattern of designed antenna at frequency 6.93 GHz

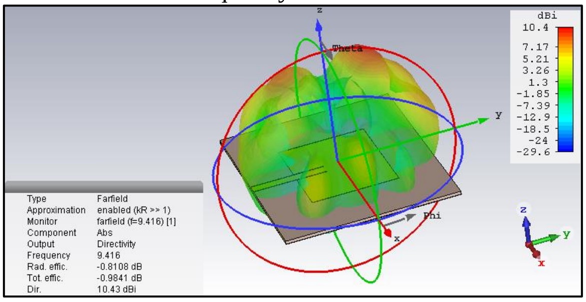

Fig. 21: 3 D radiation pattern of designed antenna at frequency 9.416 GHz

Ideally, VSWR must lie in the range of 1-2 which is achieved at different frequencies over a frequency range from 2 to 11 GHz as shown in Fig. 22. The value of VSWR achieved for resonant frequencies 2.387 GHz, 4.026GHz, 4.576 GHz, 6.93 GHz and 9.416 GHz are 1.60, 1.18, 1.28, 1.51 and 1.47 respectively.

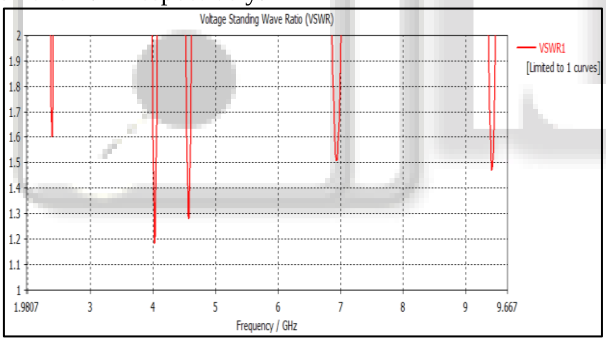

Fig. 22: VSWR of designed microstrip patch antenna over frequency range 2 to 11 GHz

IV. CONCLUSION

The work in this thesis focused on the design of a multiband inset feed microstrip patch antenna. The proposed multiband parch antenna is having good value of return loss, VSWR, gain, directivity and bandwidth at different resonant frequencies 2.387 GHz, 4.026GHz, 4.576 GHz, 6.93 GHz and 9.416 GHz. These resonant frequencies belong to S band (2 to 4 GHz), C band (4 to 8 GHz) and X band (8 to 12 GHz) applications as per designated by IEEE standard therefore the designed multiband patch antenna is best suited for S band, C band and X band applications.

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