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DESIGN OF A PATCH ANTENNA ARRAY FOR THE 2.4GHz ISM BAND

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ABSTRACT

A coaxial fed patch antenna array for application in the 2.4GHz ISM band was implemented using the Ansoft HFSS software. Standard formulae were used to calculate the different parameters of the antenna. These were just used as a basis of design as some parameters varied considerably during simulation. A good extent of the antenna design was hence done through trial and error. The proposed antenna was designed to work at 2.44 GHz frequency band. A fractional bandwidth of 2.62%, which was not close to the desired 10% and a reflection coefficient of -18.2131dB were attained. This may have been brought about by poor impedance matching and a high level of spurious feed radiation and surface waves. A way of improving the bandwidth would have been to use proximity coupling feeding method which offers the highest bandwidth (as high as 13%) and is somewhat easy to model and has low spurious radiation. However, its fabrication would have been more difficult. A directivity of 8.53dB was achieved. This was a fairly high though directivity increase could have been studied through use of different substrate material and thickness.

Key words: *patch, radiation, antenna parameter.*

1. Introduction

An antenna is a transducer between a guided wave and a radiated wave, or vice versa. The structure that "guides" the energy to the antenna is most evident as a coaxial cable attached to the antenna. A patch antenna is a type of radio antenna with a low profile, which can be mounted on a flat surface. It consists of a flat sheet of metal, usually copper, mounted on a larger sheet of metal called a ground plane. A patch array antenna is, in general, some arrangement of multiple patch antennas that are all driven by the same source. Frequently, this arrangement consists of patches arranged in orderly rows and columns (a rectangular array). The reason for these types of arrangements is higher gain. Higher gain commonly implies a narrower beamwidth and that is, indeed, the case with patch arrays.[1]

This paper the design and analysis of patch network antenna array for the 2.4GHz ISM bandwidth is largely license exempt and can be accessed freely for example bluetooth. The antenna will be designed with an aim of achieving high directivity and at least a 10% fractional bandwidth. The antenna will have a center frequency of 2.44 which is almost the same as the given ISM band center frequency. It was so chosen so as to have a bandwidth whose range is falls within the 2.4 GHz band. A basic 4 element patch antenna array was designed without much emphasis on the gain, directivity or bandwidth.

2. Patch antenna configuration and design

A rectangular patch was chosen as the basis of the design because of its ease of fabrication and analysis. The microstrip line was used as the feeding method as it is easy to fabricate, simple to match by controlling the inset feed position and rather simple to model. The antenna was designed to work in the 2.4GHz ISM band which has a frequency range of 2.4-2.5GHz, a center frequency of 2.450GHz, a bandwidth of 100MHz and is freely available worldwide. Some applications in the 2.4GHz ISM band include the home microwave oven, sulphur lamps, communication applications such as wireless LANs, bluetooth and radio control equipment such as low power remote control of toys [2].

Design Procedure:

The FR4 Glass Epoxy, whose loss tangent is 0.002, was chosen as the dielectric material substrate.

To commence the design procedure assumes, specific information had to be included: dielectric constant of the substrate (ε_r), the resonant frequency $(f_r)$and the height of the substrate, h.

$\varepsilon_r = 4.3 \;\; , f_r = 2.44GHz, \;\; h = 1.6mm$

For an efficient radiator, the practical width that leads to good radiation efficiencies is

$$W = \frac{1}{2f_r\sqrt{\mu_o\varepsilon_o}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_o}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (3-1)$$

$= 37.58mm$

where $v_o$is the free-space velocity of light.

The initial values (at low frequencies) of the effective dielectric constant are referred to as the *static values*, and they were calculated as

$W/h > 1$

$$\varepsilon_{reff=}\frac{\epsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1+12\frac{h}{W}]^{-\frac{1}{2}} \qquad (3-2)$$

$= 3.99$

A very popular and practical approximate relation was then used to find the normalized extension of the length as

$$\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \qquad (3-3)$$

$$\Delta L = 0.741mm$$

The actual length of the patch was determined by solving L as,

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_o\varepsilon_o}} - 2\Delta L \qquad (3-4)$$

$$= 29.15mm$$

For efficient transfer of power from a transmission line to the patch antenna, the input impedance of the patch antenna needed to be matched to the characteristic impedance of the transmission line. It was observed that impedance seen by a transmission line attached to the radiating edge was very high, and also the impedance (ratio of voltage to current) decreased as one moved towards the center of the patch. Therefore, depending on the characteristic impedance of the transmission line, an appropriate point on the patch was chosen through calculation as the feed point [4].

In order to access the appropriate impedance point on the patch, a recess was created in the patch. The recess or inset feed was used to improve the impedance matching between the patch and the feed line. The inset feed position, where the input impedance was 50 ohms and the lengths and widths for the microstrip feeds were calculated using the Matlab. A FDTD-Finite Difference Time Domain- analysis shows that the inset disturbs the transmission line or cavity model and increases the impedance variation with distance compared to a coaxial probe feed given a patch resonant length L and feed position y_o from the center. Transmission line analysis method was applied as it gives a good insight. However, it is more difficult to model coupling as well as less accurate [1, 3, 4].

3: Simulation:

The antenna array was designed using the Ansoft HFSS software. HFSS is a 3D full wave electromagnetic field simulator. It uses the finite element method together with adaptive meshing to solve the wave equations. If a 3D model has been made, HFSS sets up the mesh automatically. HFSS computes S-parameters, can calculate and plot both the near and far field radiation and compute important antenna parameters such as gain and radiation efficiency. This software was used to vary the sizes of the patches, microstrip feed lines and ground plane in order to come up with the desired results [5]. Figure 1. illustrates the HFSS antenna model.

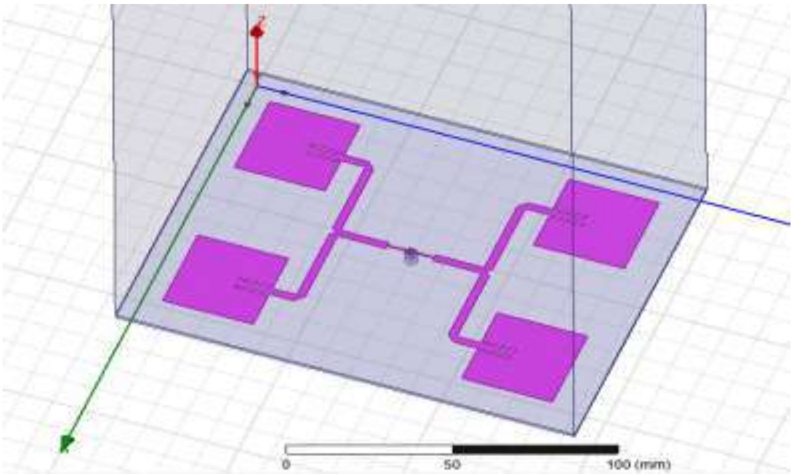

Figure 1. 4 element patch antenna HFSS model

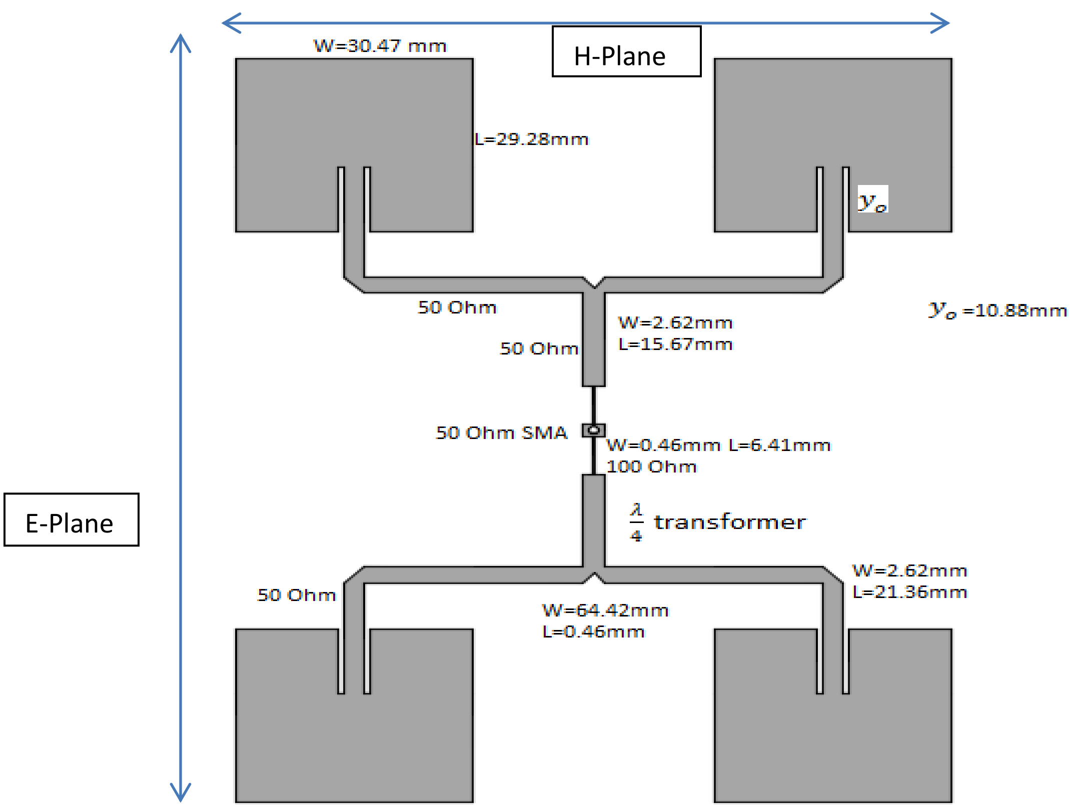

Figure 2. 4-element patch antenna PCB layout with dimensions

As per the HFSS designs, masks for fabrication of the microstrip antenna and the ground plane were designed using AutoCAD. The mask images were then transferred to transparent films before being photoengraved to a double sided PCB by exposure to UV light for 60 seconds. The PCB was then suspended in Sodium Hydroxide developer for a minute to develop photo resist. It was washed after which chemical etching done using a solution of iron chloride to create the patch antenna. The etched copper pattern was rinsed in water and again exposed to UV light for a minute. It was immersed in the developer to remove the photo resist and finally cleaned with water. After air drying, an RF RP-SMA connector (through-hole, Jack (male pin) right angle PCB mount connector) with solder post was soldered at the center of the PCB from the backside. An RG58/U cable was used to connect to the SMA connector.

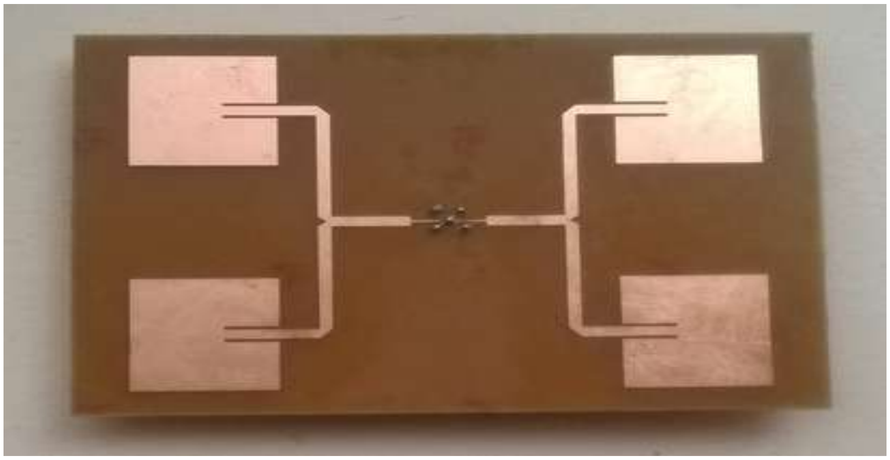

Figure3. Implemented 4-element patch antenna array

Figure 4.Ground plane of the patch antenna array

4: HFSS Simulation Result and Analysis

Variation of Patch Length and Width:

Dimensions calculated in the design procedure were used to create the 4 element array patch antenna. The antenna, however, did not produce acceptable results. In order to shift the S_{11} minima towards the desired center frequency of 2.4GHz, the length and width of the patch were shortened as follows

Table 1. Variation of antenna parameters with changes in dimensions

Length(mm)	**Width(mm)**	**Resonance Frequency(GHz)**	**Peak Directivity(dB)**
38.47	29.85	2.27	7.34
34.47	29.85	2.33	7.78
30.47	28.66	2.45	8.30
30.47	26.85	2.56	7.84
30.47	23.85	2.87	7.34

A length of 30.47mm and width of 28.66mm were selected as the S_{11} minima operated at the center frequency. It was observed that a decrease in width increased the resonance frequency. This is due to the increase in ΔL and ε_{reff}. The input impedance at resonance also increased because the radiation from the radiating edges decreases, which increases the radiation resistance. The bandwidth of the antenna decreases. There is a decrease in the directivity, efficiency, and hence gain, resulting from a decrease in the effective aperture of the antenna. Effective aperture (also known as effective area) is the area over which the antenna collects energy from the incident wave and delivers it to the receiver load [4,7].

Reflection Coefficient and Bandwidth

Figure 5. shows the reflection coefficient [S_{11}] of the proposed antenna in dB.S_{11}gives the reflection coefficient at the inset feed position where the input to the microstrip patch antenna was applied. It should be less than -10dB for an acceptable operation. It shows that the proposed antenna had a frequency of resonance of 2.44GHz [18].

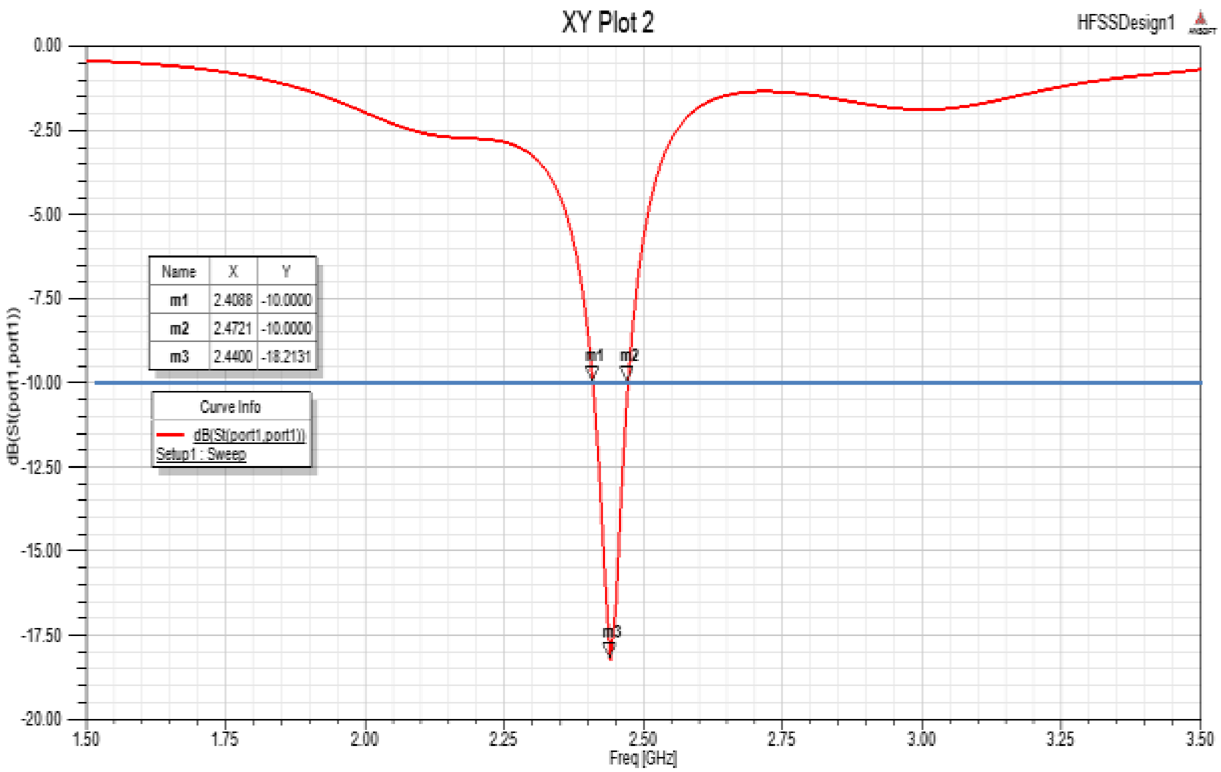

Figure 5. Return loss S_{11} obtained for the patch array

The simulated impedance bandwidth of about 63.3MHz (2.4721-2.4088 GHz) was achieved at $-10dB$ reflection coefficient (VSWR≤2). The reflection coefficient value that was achieved at this resonant frequency was equal to -18.2131 dB. This reflection coefficient value suggested that there was good matching at the frequency point below the -10dB region [8].

The fractional bandwidth achieved for the antenna was

$$BW = \frac{f_U - f_L}{f_C} \times 100\% = \frac{2.4721 - 2.4088}{2.44045} = 2.62\% \qquad (4-1)$$

where

$$f_C = \frac{f_U + f_L}{2} \qquad (4-2)$$

f_C, f_U and f_L are the center, upper and lower cutoff frequencies respectively.

Radiation Pattern

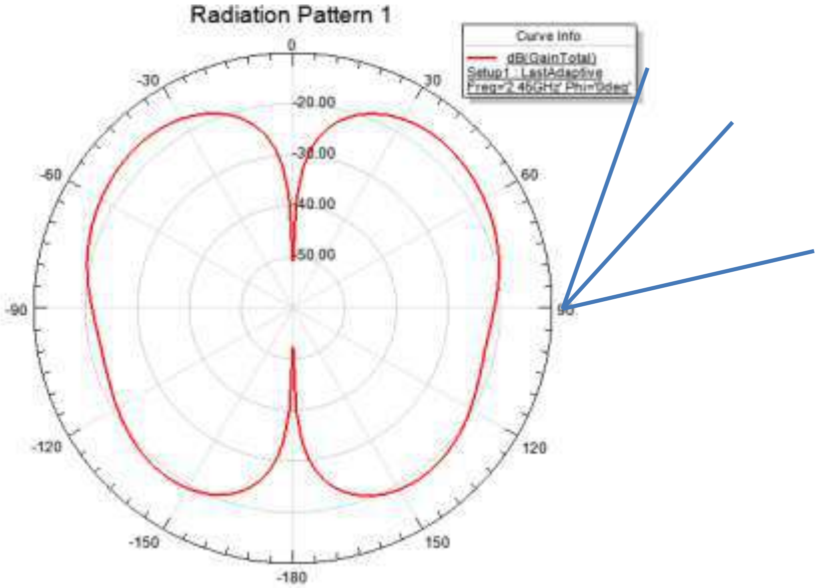

Figure 6. Simulated E-Plane (phi=90°, theta varying)

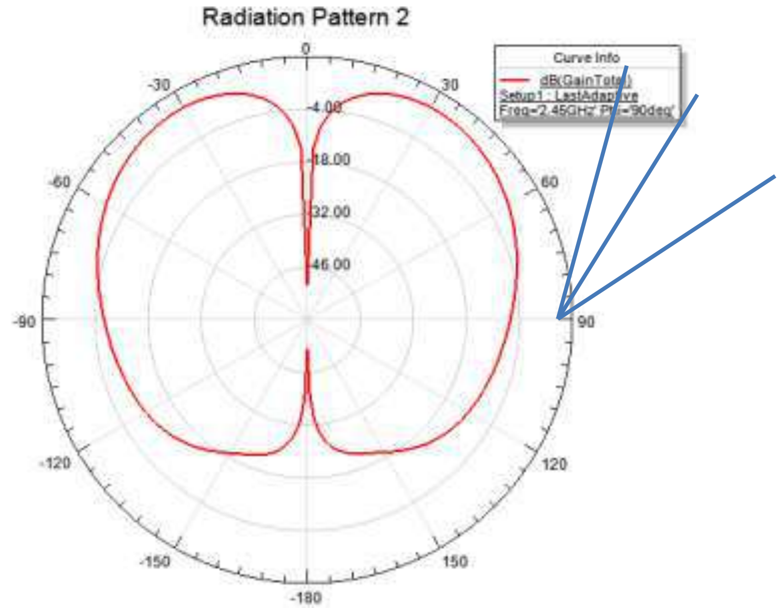

Figure 7. Simulated H-plane (theta=90°, phi varying)

The radiation patterns in the E-plane and H-plane of the patch antenna array at 2.44GHz for $y_o = 10.545mm$ are shown in Figure 6. and Figure 7. above. They are also referred to as the azimuth plane and elevation plane pattern respectively. The coplanar components in the E and H planes are E_θ in the $\Phi = 0^\circ$ and E_Φ in $\Phi = 90^\circ$ planes.

Figure 8. shows the simulated 3-D radiation pattern with gain of 5.2235 dB for proposed antenna configuration at 2.44GHz..

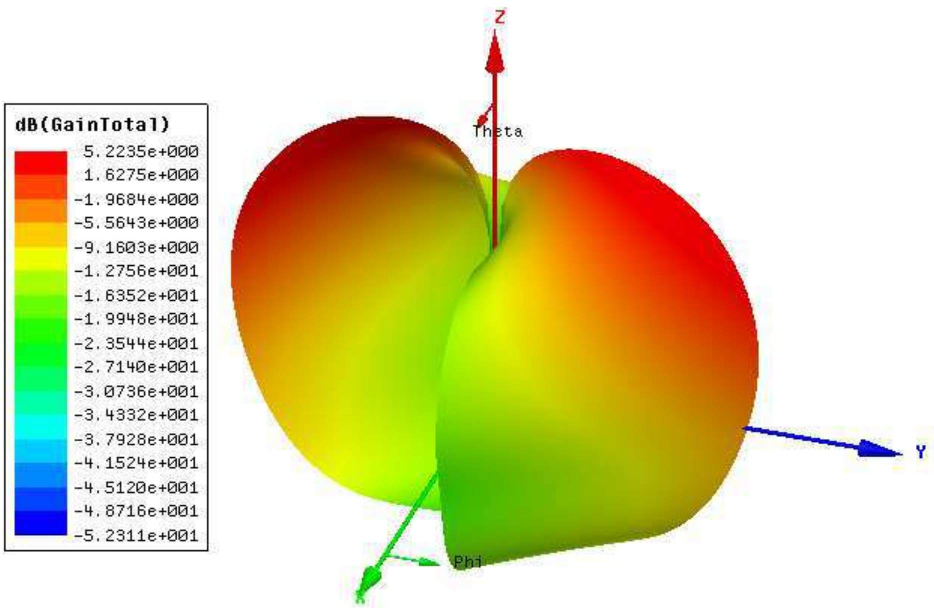

Figure 8. 3D radiation pattern

The strongest energy was radiated outward, in the yz-plane, at the widths of the patch elements and at an angle of 36°. It was observed that the antenna had an azimuth plane beamwidth of about $57^\circ$and an elevation plane beamwidth of 41°as indicated on the patterns in figures 7. and figure 8. by the blue lines. These lines were drawn where the gain was down from the peak by -3dB. The beamwidths were the total angular width between the two 3dB points on the curves. [6].

The azimuth and elevation patterns were derived by simply slicing through the 3D radiation pattern. For the azimuth plane pattern, slicing was done through thexz plane at $y = 0$, while for the elevation plane the slicing was done through the yz plane at $x = 0$.

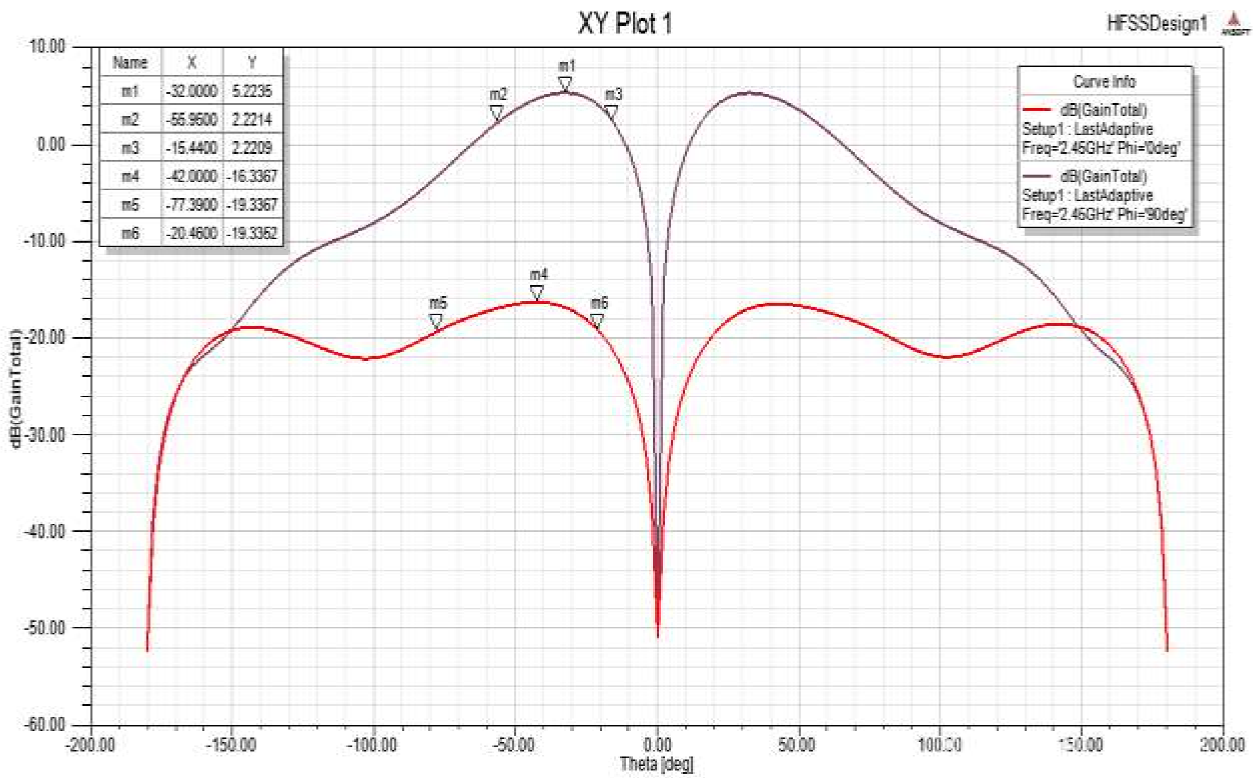

Figure 9. E-Plane and H-Plane patterns in rectangular coordinates

The Figure 9. shows that the antenna had two main lobes which were 180° out of phase with each other. It was used to determine the half-power beamwidths for the radiation patterns as the peaks and 3 dB points below them could easily be picked.

Inset Feed Position

Initially, the length of the inset feed position was calculated as $y_o = 14.15mm$ from the edge of the antenna. The slot width was chosen as 3.62mm which was 1mm greater than that of the microstrip feed. An increase in the width of the slot brought about an increase in the resonance frequency. The microstrip feed going into the patch element was 15.67mm in length which is equal to $\lambda/4$ wavelength. The resulting resonance frequency was below the desired value hence the length had to be increased as shown below

Table 2. Variation of resonance frequency with changes in patch feed length

Length of Feed(mm)	Resonance Frequency(GHz)
15.67	1.77
18.67	2.26
20.67	2.29
25.67	3.29

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The feed length of 18.67mm was chosen for analysis as it was closer to the center frequency and also not too long.

Changing of the inset feed position y_o affected the resonance frequency of the patch antenna. The longer the length, the lesser the resonance frequency became and vice versa. Lesser directivity, gain as well as magnitude of the S_{11}parameter were realized when a longer length was used.

VSWR Plot

Figure 10. shows the VSWR (Voltage Standing Wave Ratio) plot for the designed antenna. The value of the VSWR should lie between 1 and 2. SWR is used as an efficiency measure for transmission lines, electrical cables that conduct radio frequency signals, used for purposes such as connecting radio transmitters and receivers with their antennas, and distributing cable television signals [18].

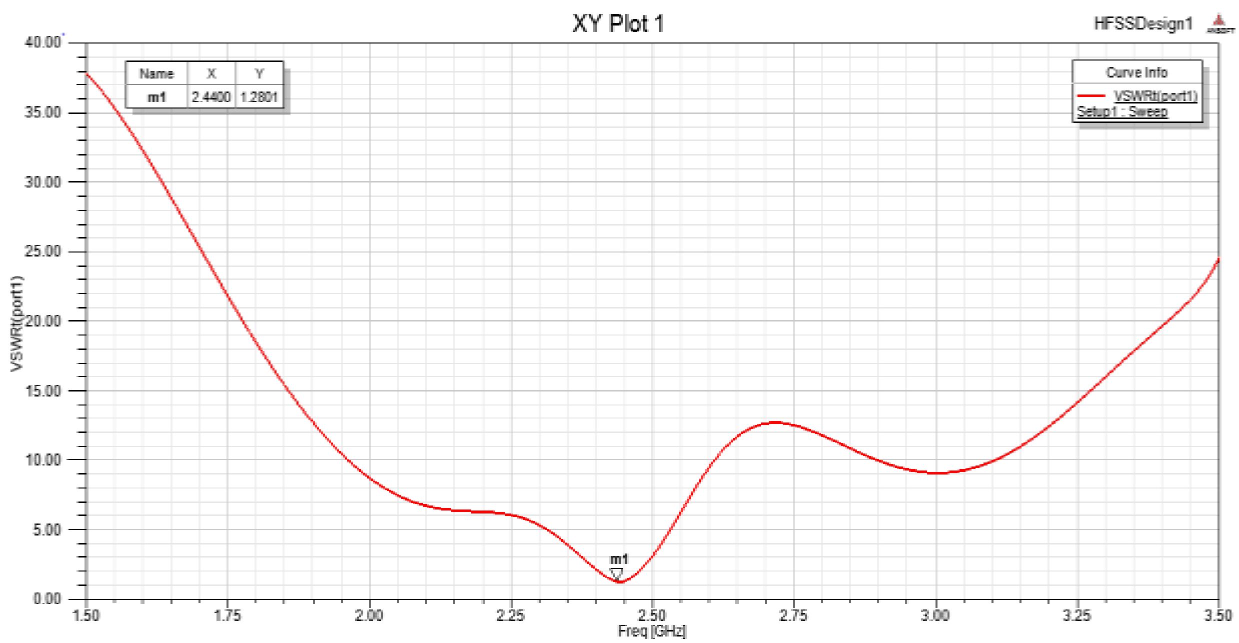

Figure 10. VSWR plot Here the value for the proposed microstrip patch antenna was1.2801 at the resonating frequency of 2.44GHz.

Smith Chart

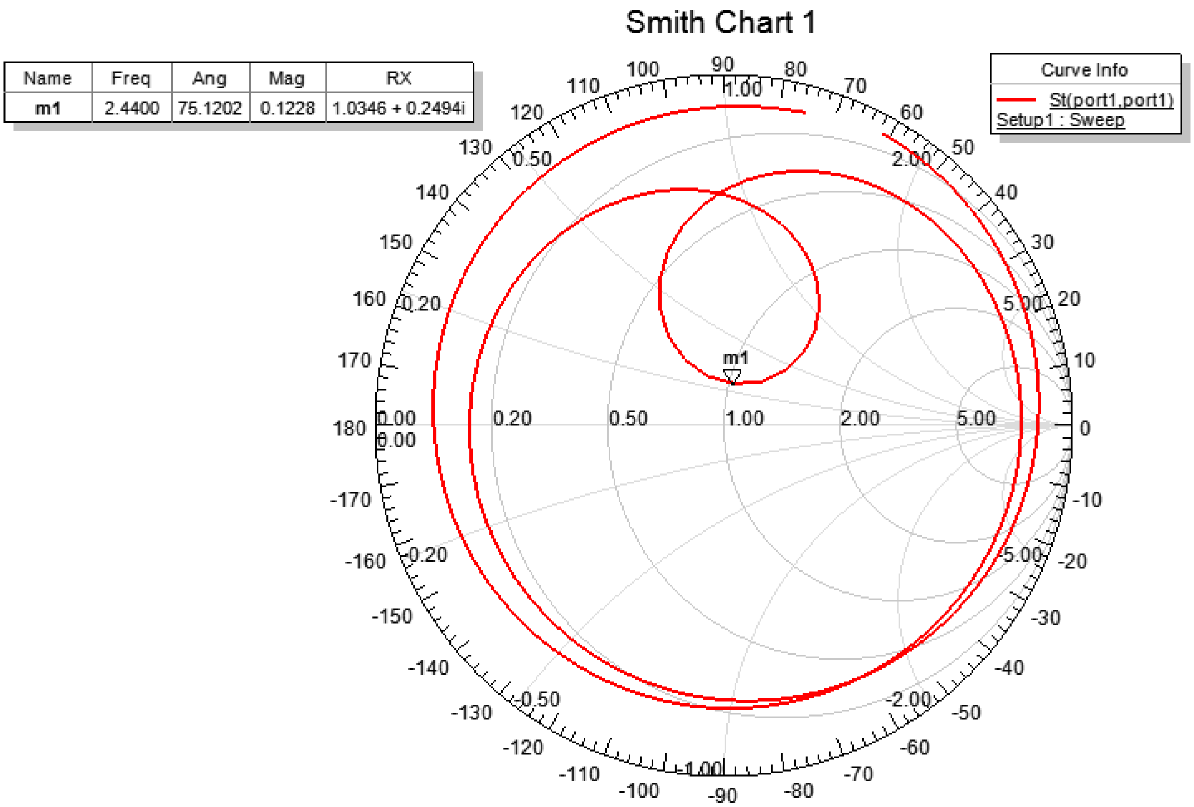

Figure 11. Smith chart of the proposed patch antenna

The smith chart is a graphical representation of the normalized characteristic impedance. It provides the information about the impedance match of the radiating patch. The smith chart for the designed patch antenna array showed an input impedance of 51.73+12.47i ohms at resonant frequency 2.44GHz. The magnitude of the input impedance was 53.21 which showed that accurate machine was not achieved. This was due to shifting of the inset feed position away from the center of the patch element which was done in order to improve the directivity, gain and return coefficient of the antenna.

5: Conclusion

A 4 element, microstrip fed patch antenna array of rectangular shaped radiating elements was successfully designed and implemented using the FR4 Epoxy Glass substrate. Through analysis with the Ansoft HFSS simulation software, it was observed that the antenna worked in the 2.4GHz ISM band by having a resonance frequency of 2.44GHz, and had a fractional bandwidth of 2.26% and a directivity of 8.53dB. The proposed antenna is useful for wireless communication systems.

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