Dual Frequency Hexagonal Microstrip Patch Antenna

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***Abstract*—** The study of Microstrip patch antennas have made great progress in recent years. Compared with conventional antennas, Microstrip patch antennas have more advantages and better prospects. They are lighter in weight, low volume, low cost, low profile, smaller in dimension and ease of fabrication and conformity. Moreover, the Microstrip patch antennas can provide dual and circular polarizations, dual-frequency operation, frequency agility, broad band-width, feed line flexibility, and beam scanning omnidirectional patterning. In this paper we discuss the Microstrip antenna, types of Microstrip antenna, feeding techniques and application of Microstrip patch antenna with their advantage and disadvantages and the benefits of using slots.

Index Terms- Antenna, Slots, MSA, Dielectric, Patch, Substrate, Feed.

I. Introduction

An **antenna** is an electrical device which converts electric power into radio waves, and vice versa. It is usually used with a radio transmitter or radio receiver.

I.1 Microstrip Patch Antenna

The study of Microstrip patch antennas has made great progress in recent years. Compared with conventional antennas, Microstrip patch antennas have more advantages and better prospects. They are lighter in weight, low volume, low cost, low profile, smaller in dimension and ease of fabrication and conformity. Moreover, the Microstrip patch antennas can provide dual and circular polarizations, dual-frequency operation, frequency agility, broad band-width, feed line flexibility, and beam scanning omnidirectional patterning. Few points-

- 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.
- 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.

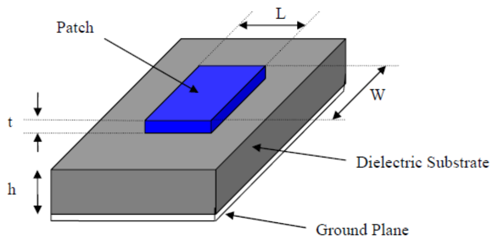


Fig:-1 Structure of Microstrip Patch Antenna

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, elliptical or some other common shape as shown in figure below. For a rectangular patch, the length L of the patch is usually $0.3333\lambda 0 < L < 0.5\lambda 0$, where $\lambda 0$ is the free-space wavelength. The patch is selected to be very thin such that $t << \lambda 0$ (where t is the patch thickness). 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 (εr) is typically in the range $2.2 \leq \varepsilon r \leq 12$.

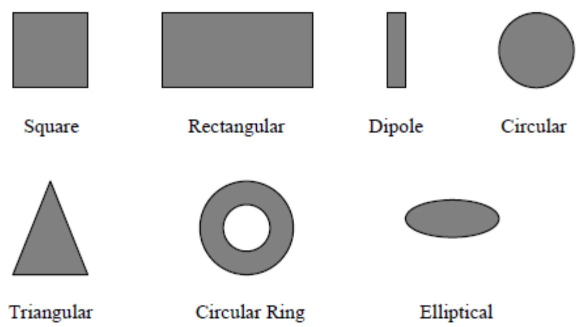


Fig-2 Common shapes of Microstrip Patch Elements

Advantages:-
Microstrip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Therefore they are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc. The telemetry and Square Rectangular Dipole Circular Triangular Circular Ring Elliptical 33 communication antennas on missiles need to be thin and conformal and are often Microstrip patch antennas. Another area where they have been used successfully is in Satellite communication. Some of their principal advantages are:
• Light weight and low volume.
• Low profile planar configuration which can be easily made conformal to host surface.

• Low fabrication cost, hence can be manufactured in large quantities.
• Supports both, linear as well as circular polarization.
• Can be easily integrated with microwave integrated circuits (MICs).
• Capable of dual and triple frequency operations.
• Mechanically robust when mounted on rigid surfaces.

Disadvantages:-
Microstrip patch antennas suffer from a number of disadvantages as compared to conventional antennas. Some of their major disadvantages are:
• Narrow bandwidth
• Low efficiency
• Low Gain
• Extraneous radiation from feeds and junctions
• Poor end fire radiator except tapered slot antennas
• Low power handling capacity.

I.2 Feed Techniques

1. **Microstrip Line Feed:** In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch.

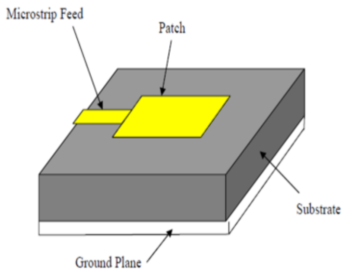


Figure Microstrip Line Feed

Fig:- 3

2. **Coaxial Feed:** In this type of feed technique, a coaxial feed is used. The inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane.

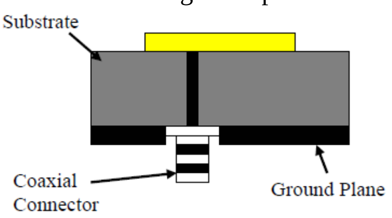


Figure Probe fed Rectangular Microstrip Patch Antenna

Fig:- 4

3. **Aperture Coupled Feed:** In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

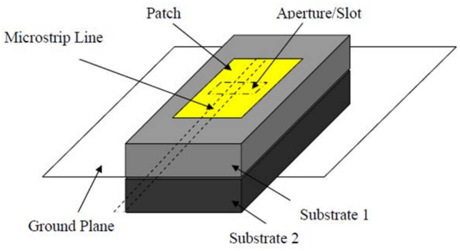


Figure Aperture-coupled feed

Fig:- 5

4. **Proximity Coupled Feed:** In this type of feed technique, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate.

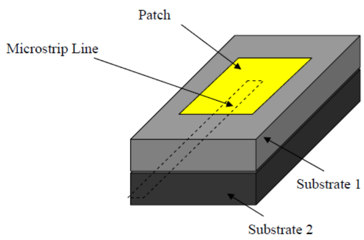


Figure Proximity-coupled Feed

Fig:- 6

II. Proposed Work

In this paper we provide the comparative study of Hexagonal Microstrip Antenna, its disadvantages and it has been overcome by Dual Frequency Hexagonal Microstrip Patch Antenna using Slots.

II.1 Hexagonal Microstrip Antennas(HMSA)

For the given patch dimension, the HMSA has higher resonance frequency as compared to RMSA. The modal distributions of HMSA are studied and it was observed that HMSAs distribution is similar to the modal distributions of circular MSA (CMSA). Therefore by equating the areas of HMSA and CMSA the resonance frequency formulation for HMSA is proposed. The formulations obtained using this method agrees closely with the simulated results for fundamental as well as higher order modes.

The HMSA is shown in Fig. 1(a). It is obtained from equivalent RMSA by changing the side length S as shown in Fig. 1(a). In this all the side lengths are not equal. A regular HMSA has all equal side length as shown in Fig. 1(b). For the dimensions shown in Fig. 1(a), the first and second order resonance frequencies are 1113 and 1425 MHz as shown in their current distributions in Fig. 2(a, b). Similarly for regular HMSA, the frequencies are 915 and 1516 MHz as shown in their surface current distributions in Fig. 2(c, d). These current distributions are similar to the current distributions of TM_{11} and TM_{21} modes in CMSA. Due to this similarity between the distributions of HMSA and CMSA, the resonance frequency formulation for HMSA is derived using frequency equation for CMSA as given below.

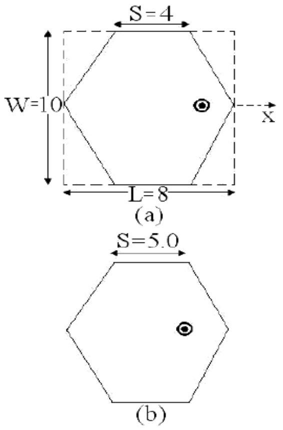


Fig. 1 (a) HMSA and its equivalent RMSA and (b) regular HMSA

Fig:- 7

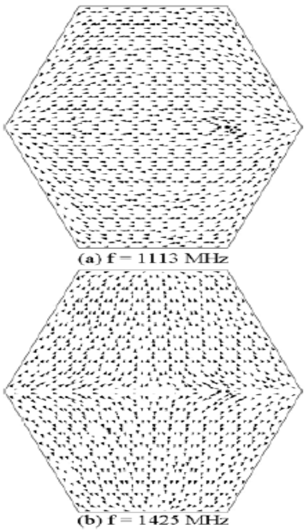


Fig:- 8

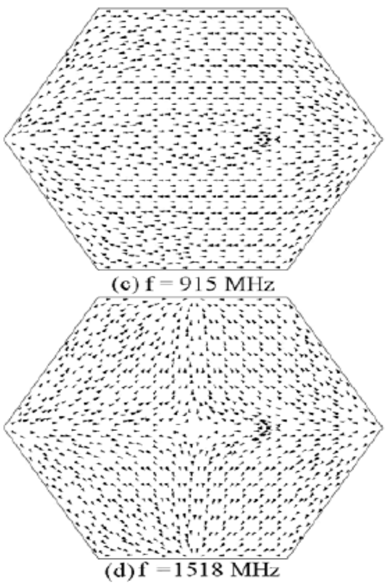


Fig. 2 Surface current distribution at first two frequencies for (a, b) HMSA and (c, d) regular HMSA

Fig:- 9

The formulation is proposed for HMSA as well as regular HMSA. The area of HMSA (a_h) is first calculated and it is equated with the area of equivalent CMSA (a_c). Further the equivalent radius of the CMSA in terms of side length of HMSA is calculated. This equivalent radius is used in the resonance frequency equation of CMSA to formulate the resonance frequency of HMSA as given in equation (7).

for regular HMSA,

$$a_H = 2.598S^2 \qquad (1)$$

$$a_C = \pi r_c^2 \qquad (2)$$

Equating the two areas gives,

$$r_c = S\sqrt{2.598/\pi} \qquad (3)$$

for HMSA,

$$a_H = SW + \frac{(L-S)W}{2} \qquad (4)$$

$$a_C = \pi r_c^2 \qquad (5)$$

$$r_c = \sqrt{a_H/\pi} \qquad (6)$$

$$f_r = \frac{K_{mn}c}{2r_c\pi\sqrt{\varepsilon_r}} \qquad (7)$$

where,

a_H = area of HMSA

a_C = area of CMSA

r_C = equivalent radius of CMSA

K_{mn} = 1.84118 (TM_{11} mode), 3.05424 (TM_{21} mode)

Performance Parameters:

The performance of an antenna can be measured by a number of parameters. The followings are the critical ones.

(a)Radiation Pattern: The antenna pattern is a graphical representation in three dimensional of the radiation of the antenna as the function of direction. It is a plot of the power radiated from an antenna per unit solid angle which gives the intensity of radiations from the antenna. If the total power radiated by the isotropic antenna is P, then the power is spread over a sphere of radius r, so that the power density S at this distance in any direction is given as:

$$S = \frac{P}{4\pi R^2}$$

Then the radiation intensity for this isotropic antenna Ui can be written as:

$$U_i = \frac{P}{4\pi}$$

Isotropic antennas are not realizable in practice but can be used as a reference to compare the performance of practical antennas. The radiation pattern provides information on the antenna beam width, side lobes and antenna resolution to a large extent. The E plane pattern is a graphical representation of antenna radiation as a function of direction in a plane containing a radius vector from the center of the antenna to the point of maximum radiation and the electric field intensity vector. Similarly the H plane pattern can be drawn considering the magnetic field intensity vector

(b) Gain: Antenna gain is the ratio of maximum radiation intensity at the peak of main beam to the radiation intensity in the same direction which would be produced by an isotropic radiator having the same input power. Isotropic antenna is considered to have a gain of unity. The gain function can be described as:

$$G(\theta,\emptyset) = \frac{P(\theta,\emptyset)}{\frac{Wt}{4\pi}}$$

where$(\theta,\emptyset)$ is the power radiated per unit solid angle in the direction$(\theta,\emptyset)$ and Wt is the total radiated power. Microstrip antennas because of the poor radiation efficiency have poor gain. Numerous researches have been conducted in various parts of the world in order to obtain high gain antennas.

(c) Directivity: If a three dimensional antenna pattern is measured, the ratio of normalized power density at the peak of the main beam to the average power density is called the directivity. The directivity of the antenna is given by:

$$D = \frac{P_{max}}{P_{avg}}$$

The relation between directivity and gain can be given as:

G=ƞD, where ƞ is the antenna efficiency.

(d) Bandwidth: It is defined as "The range of usable frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard." The bandwidth can be the range of frequencies on either side of the center frequency where the antenna characteristics like input impedance, radiation pattern, beam width, polarization, side lobe level or gain, are close to those values which have been obtained at the center frequency. The bandwidth of narrow band and broadband antennas are defined as:

$$BWbroadband = \frac{F_h}{F_l}$$

$$BWnarrowband\,\% = \frac{F_h - F_l}{F_c} \times 100$$

Where F_h is the upper frequency, F_l is the lower frequency and F_c is the center frequency.

(e) Return Loss: Return loss or reflection loss is the reflection of signal power from the insertion of a device in a transmission line or optical fiber. It is expressed as ratio in dB relative to the transmitted signal power. The return loss is given by:

$$\boldsymbol{R_l(dB) = 10log(\frac{P_r}{P_i})}$$

Where Pi is the power supplied by the source and Pr is the power reflected.

If Vi is the amplitude of the incident wave and Vr that of the reflected wave, then the return loss can be expressed in terms of the reflection coefficient τ as:

$$Rl = -20log|\Gamma|,$$

And the reflection coefficient Γ can be expressed as:

$$\Gamma = \frac{V_r}{V_i}$$

For an antenna to radiate effectively, the return loss should be less than$-10\ dB$.

(f) VSWR: A standing wave in a transmission line is a wave in which the distribution of current, voltage or field strength is formed by the superimposition of two waves of same frequency propagating in opposite direction. Then the voltage along the line produces a series of nodes and antinodes at fixed positions.

If $V\ (z)$ represents the total voltage on the line then

$$V(z) = V^{+}e^{-j\beta z} + V^{-}e^{+j\beta z}$$

Then the Voltage Standing Wave Ratio (VSWR) can be defined as:

$$VSWR = \frac{Vmax}{Vmin} = \frac{1+|\Gamma|}{1-|\Gamma|}$$

The value of VSWR should be between 1 and 2 for efficient performance of an antenna.

Antenna Design

In this project, the modal distributions of HMSA are studied and it was observed that HMSAs distribution is similar to the modal distributions of circular MSA (CMSA). Therefore by equating the areas of HMSA and CMSA the resonance frequency formulation for HMSA is proposed. The formulations obtained using this method agrees closely with the simulated results for fundamental as well as higher order modes. Also the dual band dual polarized configuration of HMSA by cutting the rectangular slot in the center of the patch is proposed. The formulation in resonant length for dual polarized response is also proposed. The frequency values obtained using the proposed formulations agree closely with simulated results. All these MSAs were first analyzed using the IE3D software followed by experimental verification in dual band and dual polarized HMSA.

The **Neltec NX9320** substrate (ε_r = 3.2, h = 0.76 mm, tan δ = 0.0024) is used for the simulations as well as the measurements. The HMSAs are fed using microstrip line of width 1.8246 mm.

Area of a Regular hexagon (A_h) $= \frac{3\sqrt{3}}{2} s^2$

Area of a Circle (A_c) $= \pi {r_c}^2$

Equating Both the Area,

$$r_c = s \times \sqrt{\frac{2.598}{\pi}}$$

We know that the resonance frequency of circular patch antenna,

$$f_r = \frac{X_{mn}\,c}{2\pi r_c \sqrt{\epsilon_r}}$$

The Resonance frequency of regular hexagon,

$$f_r = \frac{X_{mn}\,c}{2\pi s\sqrt{\frac{2.598}{\pi}}\sqrt{\epsilon_r}}$$

$$s = \frac{c}{3.1033 f_r \sqrt{\epsilon_r}}$$

For TM_{11} Mode X_{11} =1.84118
For TM_{21} Mode X_{21} =3.05424

The Operating Frequency (f_r) of the Hexagonal Patch is taken to be 3.8 GHz
Putting this in the above Eq we get,

Radius of the patch, $s = 14.22\,mm$
Inset Feed width, $W_l = 1.8246\,mm$
Cut Width, $2W_l = 3.6492\,mm$
Transmission Line Length $\left(\frac{\lambda}{4}\right) = 19.7368$

After finding the patch size the antenna feed line should be designed. The patch antenna was matched to $Z_o = 50\ \Omega$ transmission lines where two matching methods were considered: inset feed and quarter wave transformer. Matching reduces the loss of the signal and reflected power towards the transmission line that supplies a smooth transition of energy from the antenna input impedance to the feed line. The program also provided the input impedance at the edge of the patch antenna $Z_{in} = 204.75\ \Omega$. The quarter wave transformer was designed theoretically by first calculating its characteristic impedance as:

$$Z_1 = \sqrt{Z_0 Z_{in}} \approx 101.181\ \Omega$$

Inserting the appropriate collected data into the transmission line calculator, the desired length and width of the quarter wave transmission line was calculated. Furthermore, utilizing the inset-feed length was found as:

$$y_0 = \frac{W}{\pi} cos^{-1}\sqrt{\frac{Z_0}{Z_1}}$$

Putting the value of $W = 24.629\,mm$

We get $y_0 = 6.2031\,mm$

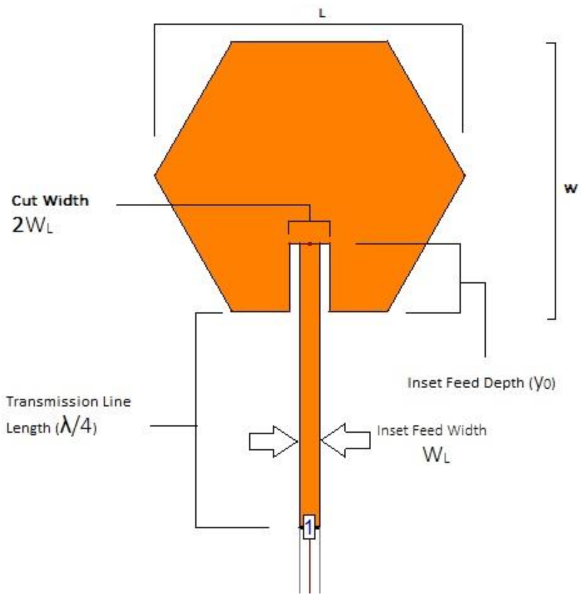


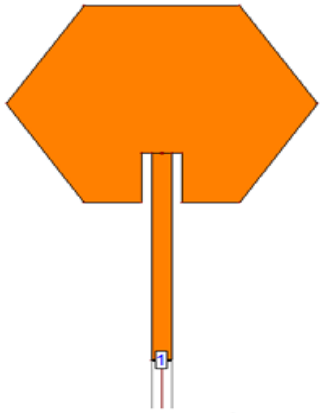
Fig:- 10

<u>Hexagonal Microstrip Patch Antenna</u>

III. Simulated Results and Discussion

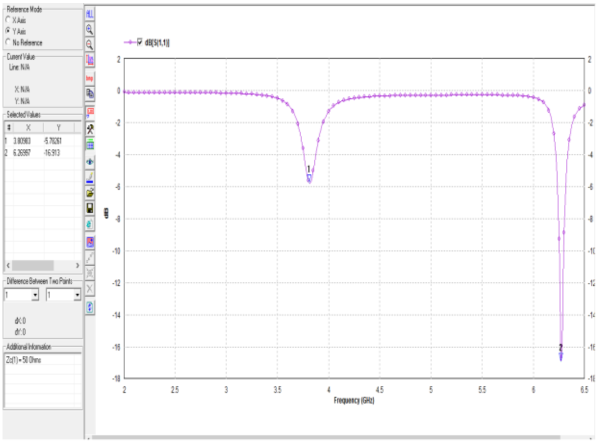
❖ Hexagonal Microstrip Patch Antenna

The Above design of Hexagonal Microstrip Patch Antenna was simulated using Zeland Ie3D 14.0.



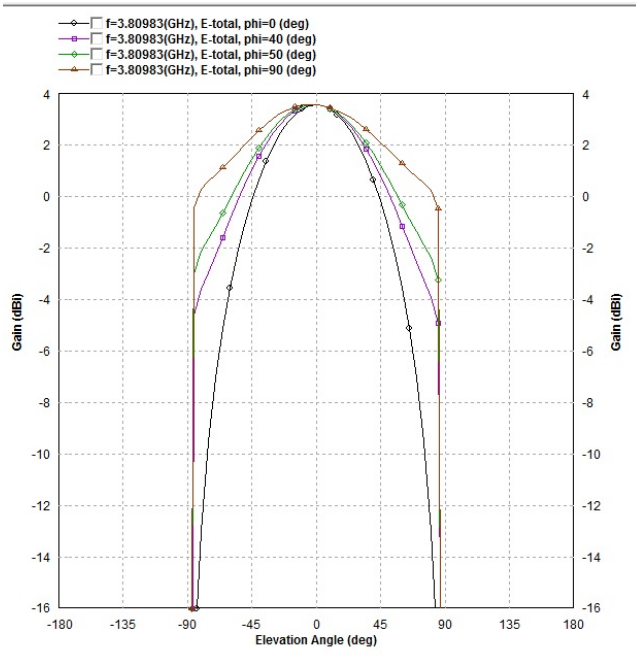
1. HEXAGONAL MICROSTRIP PATCH ANTENNA

Fig:- 11



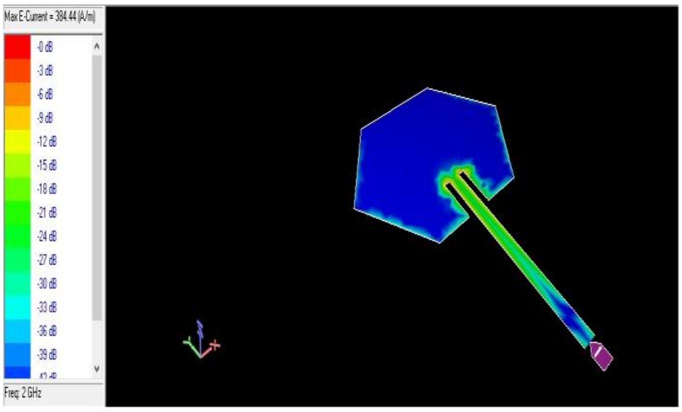
2. RETURN LOSS

Fig:- 12



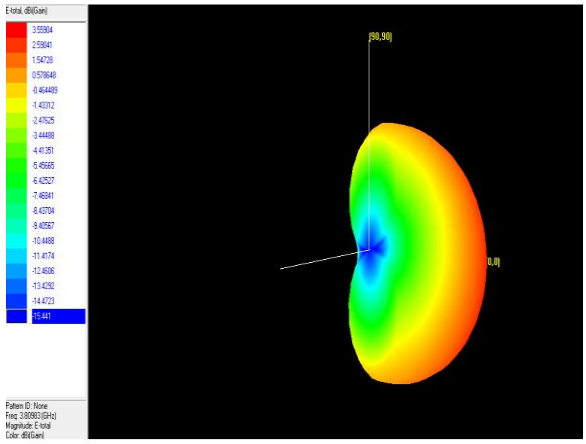
3. 2D PATTERN

Fig:- 13



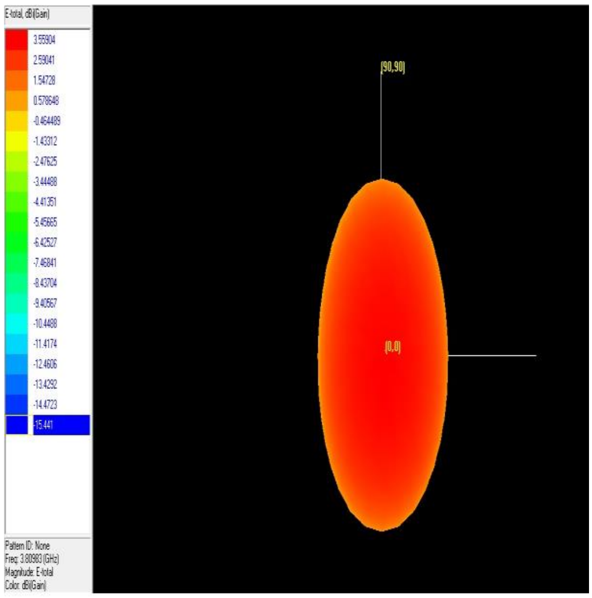
4. CURRENT DISTRIBUTION

Fig:- 14



5. 3D PATTERN (SIDE VIEW)

Fig:- 15



6. 3D PATTERN (TOP VIEW)

Fig:- 16

OBSERVATION:

- The Return Losses at 3.80983 GHz and 6.26937 GHz were -5.78261 dB and -16.913 dB respectively

- The Gain at 3.80983 GHz and 6.26937 GHz were 3.55904 dB and 3.20694 dB respectively

CONCLUSION:

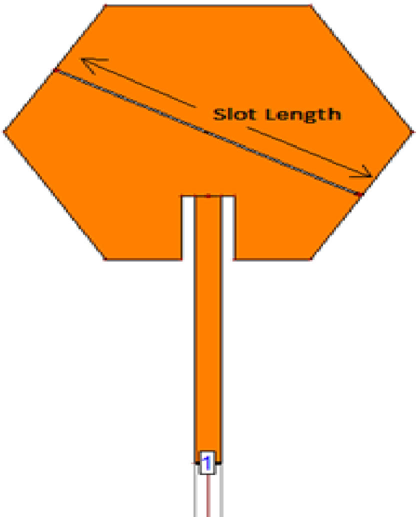
- The above simulated results are not satisfactory as the antenna is working in a single band.

- The antenna is not working in a license free band.

And our aim is to design a dual frequency microstrip antenna working in a license free band and therefore slot is introduced.

II.2 Dual Frequency Hexagonal Microstrip Patch Antenna using Slots

The multi-band microstrip antenna (MSA) is realized by using the techniques of placing an open circuit or short circuit stub on the edges of the patch or by cutting the slot at an appropriate position inside the patch. Of these two methods, the slot method is more frequently used since it realizes dual band response without increasing the overall patch size. The dual polarized response is realized when the patch mode and the mode introduce by the slots are orthogonal to each other.

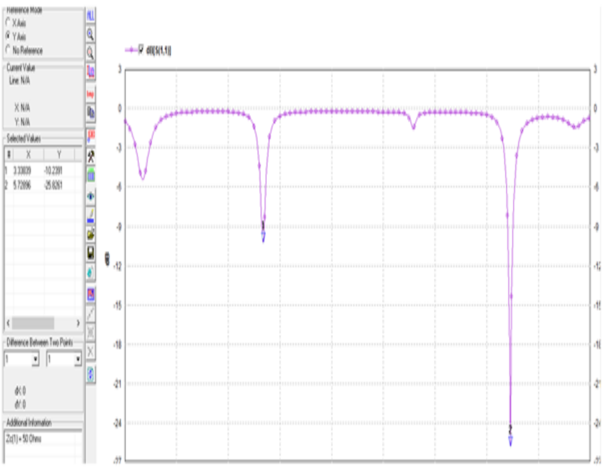


HEXAGONAL MICROSTRIP PATCH ANTENNA USING SLOT

Fig:- 17

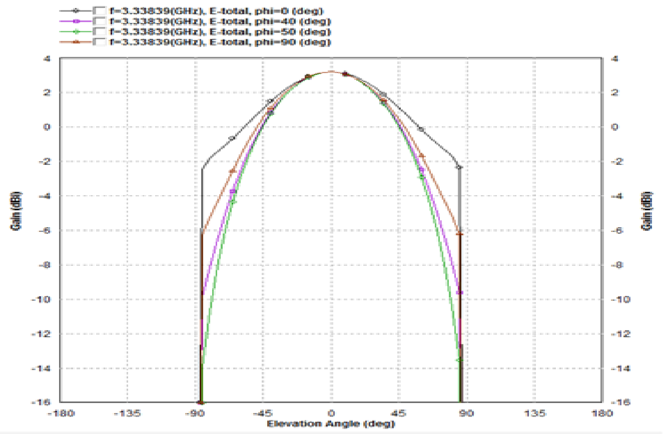
Simulated results and discussion:

❖ **Hexagonal Microstrip Patch Antenna using Slots**



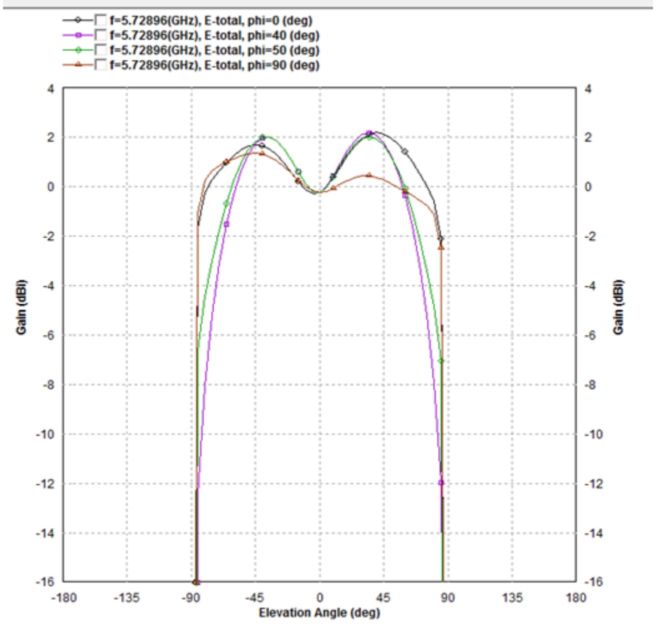
1. RETURN LOSS

Fig:- 18



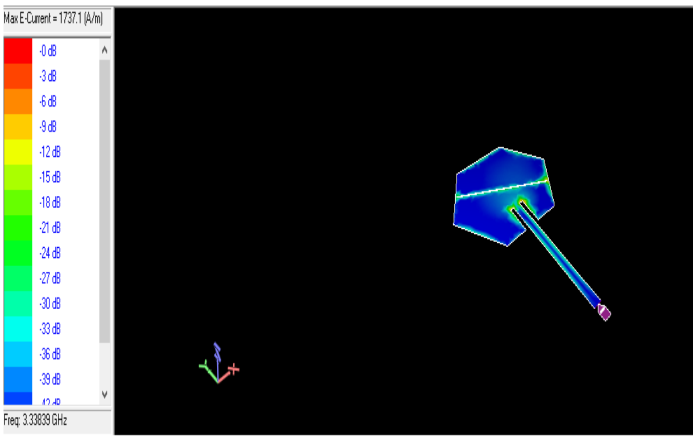
2. 2D PATTERN (Low Frequency)

Fig:-19



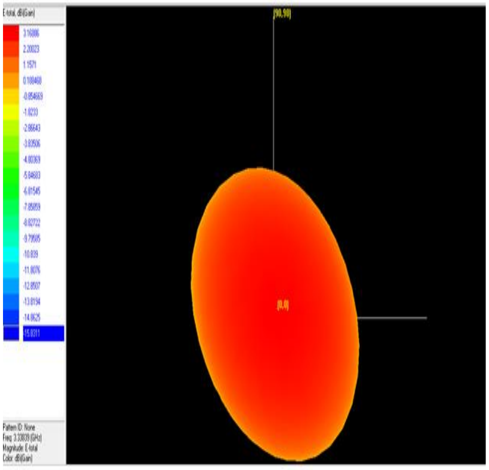
3. 2D PATTERN (High Frequency)

Fig:- 20



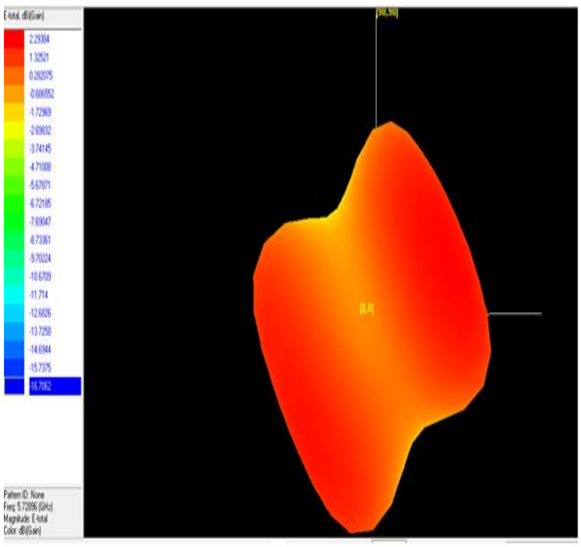
4. CURRENT DISTRIBUTION

Fig:- 21



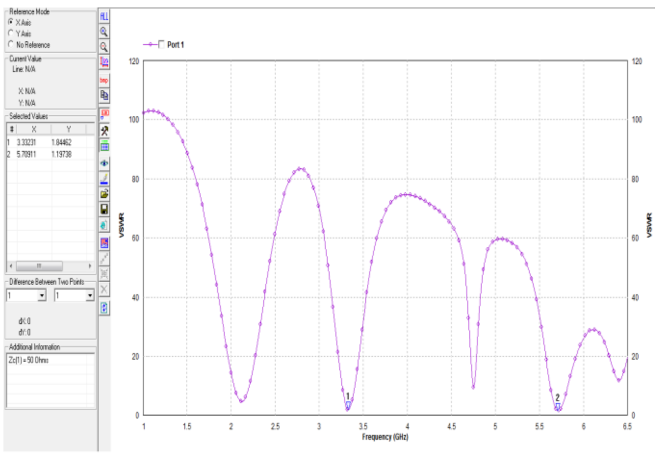
5. 3D PATTERN (Low Frequency)

Fig:- 22



6. 3D PATTERN (High Frequency)

Fig:- 23



7. VSWR REPRESENTATION

Fig:- 24

OBSERVATION:

- The Return Losses at 3.33839 GHz and 5.72896 GHz are -10.2391 dB and -25.8261 dB respectively.

- The gain at 3.33839 GHz and 5.72896 GHz are 3.16886 dB and 2.29384 dB respectively.

IV. CONCLUSION

The resonance frequency formulations for HMSA and regular HMSA using the CMSA equivalence are proposed. The frequency obtained using them closely matches with the simulated HMSA results. The dual polarized HMSA is proposed. The resonance frequency formulation in terms of slot dimension is proposed at f1. The frequency obtained using them closely matches the simulated frequency. Since these antennas are analyzed using Neltec NX 9320 substrate they have lower gain which can be increased using slots.
The impedance bandwidth of slotted patch is achieved more in comparisons to simple hexagonal patch antenna. The average gain achieved in slotted hexagonal patch more than simple hexagonal patch antenna and radiation efficiency achieved more in simple patch against slotted patch antenna.

- The Frequency Band in which the Antenna is working by using slot is 3.33839 GHz and 5.72896 GHz which are License free band.

- The most recent versions of both WiMAX standards in 802.16 cover spectrum ranges from at least the 2 GHz range through the 66 GHz range. The International standard of 3.3 GHz spectrum was the first to enjoy WiMAX products which is a license free band. Hence this Antenna can be used in the above frequency range.

- Wi-Fi is aimed at use within unlicensed spectrum. There are a number of unlicensed spectrum bands in a variety of areas of the radio spectrum. Often these are referred to as ISM bands - Industrial, Scientific and Medical, and they carry everything from microwave ovens to radio communications. This 5 GHz band or 5.8 GHz band provides additional bandwidth, and being at a higher frequency, equipment costs are slightly higher, although usage, and hence interference is less. It can be used by IEEE 802.11a & n.

REFERENCES:-

1. Broadband Microstrip Antenna by Girish Kumar 2003 Artech House Publisher.

2. Dual Band and Dual Polarized Microstrip Patch Antenna by Prof. S K Behera May 2010

3. Bandwidth Enhancement of Hexagonal Microstrip Patch Antenna by P.K. Gupta

ISSN 2250-3153

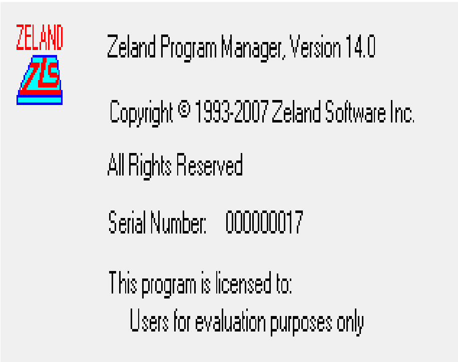
4. Design of a compact *Microstrip Patch Antenna* for use in Wireless Communication by PS Nakar – 2004.

5. http://en.wikipedia.org/wiki/Microstrip_antenna

6. www.taconic-add.com/.../technicalarticles--dual_polarised_patch_antennna

7. *www.ijecse.org/wp-content/.../01/Volume-1Number-2PP-533-537.pdf*

- **Software Description:**



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