Chapter 5 Proposed Antenna Structures

This chapter explains the different proposed geometries of antennas. Starting from first model, which represents the Stacked MPA and patch rotation effect. The behavior of lower patch is analyzed then placing the patch geometry to enhance the bandwidth criteria and loading effect is also observed.

5.1 Parametric study of a patch
Before designing a patch antenna it is very essential to study certain parameters which affect its design and performance. Say, for example if we consider a rectangular patch, parameters like length, width, etc are basis for the design. Similarly for a circular patch, radius will be the important factor to be considered [17]. So the aim of this chapter is to consider how these parameters affect the design and performance of the patch.

This section provides a generalized study of parameters affecting the antenna performance. One can easily apply these to any patch design depending on shape and feeding technique used. Variation of one parameter with other can also be easily established depending on their direct or inverse proportionalities.

5.1.1 Effect of width
The width $W$ of a rectangular patch has significant effect on different parameters of the antenna, while increasing the width of patch following effects can be observed:

- The resonant frequency decreases due to increase in $\Delta L$ (increase in length considering fringing) and $\varepsilon e$.
- The input impedance at resonance decreases as radiation resistance decreases due to increase in radiation from the width.
• With increase in width radiation resistance decreases, presented in figure 52.
• The feed point location shift towards the edge as presented in figure 53.

![Figure 52 Width Vs Radiation resistance graph](image)

![Figure 53 Feed point Vs Width graph](image)

• If aperture area increases resulting increase in gain, directivity and efficiency of patch antenna.
• Bandwidth increases and the increase can be dominantly observed when feed point location is optimized.
• The bandwidth increases with increase in the width as shown in figure 54.
5.1.2 Effect of height

The following effects can be observed when the height is increased.

- With increase in \( h \), the fringing fields increase and this results in an increased \( \Delta L \) which decreases the resonant frequency as shown in figure 55.

![Figure 54 Width Vs Bandwidth graph](image)

![Figure 55 Height Vs Effective length](image)
- The input impedance increases with increase in $h$ due to increase in probe inductance.
- The bandwidth of antenna increases when feed point location is optimized.
- The directivity of the antenna increases but efficiency decreases due to increase in cross-polar level and surface wave propagation.
5.2 Design Procedure for Rectangular Microstrip Antennas

5.2.1 Element Width

In the design consideration first step is to select dielectric material with suitable thickness. The width of patch is decided by dielectric permittivity and resonating frequency at $f_r$, as in equation 5.1

$$W = \frac{c}{2f_r} \left( \frac{\varepsilon_r + 1}{2} \right)^{\frac{1}{2}}$$ …(5.1)

Where $c =$ velocity of light.

5.2.2 Element Length

As we know the width of patch, the length can be determined from equation 5.2

$$L = \frac{c}{2f_r \sqrt{\varepsilon_e}} - 2\Delta l$$ …(5.2)

Where

$$\varepsilon_e = \frac{\varepsilon_r + 1}{\varepsilon_r - 1} \left( \frac{12h}{2} \right)^{\frac{1}{2}}$$ …(5.3)

Here $\Delta l$ is the effective length of patch which is generated because of the fringing field phenomena.

Where $\varepsilon_e$ is the effective permittivity of the material which is caused by the fringing field and the $\varepsilon_r$ is the relative permittivity of the material itself.

$$\frac{\Delta l}{h} = 0.412 \frac{(\varepsilon_e + 0.3)\left( W + 0.264 \right)}{(\varepsilon_e - 0.258)(W + 0.8)}$$ …(5.4)

5.2.3 Radiation Pattern

Radiation pattern of an antenna is most important parameter. Various mathematical models have been developed to predict the radiation characteristics of a microstrip patch radiator, and
for most engineering purpose the simple transmission line model provides adequate results.

The radiation pattern may be plotted by

H-plane radiation pattern expressed in equation 5.5

\[
F_H(\theta) = \frac{\sin\left(\frac{k_0 W}{2}\cos(\theta)\right)}{k_0 h \cos(\theta)} \sin(\theta) \quad \text{...(5.5)}
\]

E-plane radiation pattern expressed in equation 5.6

\[
F_E(\phi) = \frac{\sin\left(\frac{k_0 h \cos(\phi)}{2}\right)}{k_0 h \cos(\phi)} \cos\left(\frac{k_0 L}{2} \cos(\phi)\right) \quad \text{...(5.6)}
\]

Where \(k_0\) is constant

5.2.4 Beam width

The half power beam width is equal to the angular width between directions where the gain is decreased by 3dB, or the radiated field reduces to \(\frac{1}{\sqrt{2}}\) of the maximum value. For rectangular patch antenna after solving transmission line equation the half power beam width for H-plane and E-plane is given by following equations respectively:

\[
\theta_{BH} = 2 \cos^{-1}\left(\frac{1}{2 \left(1 + \frac{k_0 W}{2}\right)}\right)^{-\frac{1}{2}} \quad \text{...(5.7)}
\]

\[
\theta_{BE} = 2 \cos^{-1}\left(\frac{7.03}{3k_0^2 L^2 + k_0^2 h^2}\right) \quad \text{...(5.8)}
\]

5.2.5 Directivity and gain

The directivity is always greater than one, since an isotropic radiator is not directional. The directivity of patch antenna is defined as

\[
D = \frac{1}{2} \Re\left(\frac{H^* - E^*}{P_{_0}}\right) \quad \text{...(5.9)}
\]
\[
E_\theta = \text{Electric field component in } \theta \text{ direction}
\]
\[
H^*_\phi = \text{Complex conjugate of Magnetic field component in } \phi \text{ direction}
\]
\[
E_\phi = \text{Electric field component in } \phi \text{ direction}
\]
\[
H^*_\theta = \text{Complex conjugate of Magnetic field component in } \theta \text{ direction}
\]
\[
Pr = \text{radiated power},
\]
\[
\eta_0 = 120\pi \text{ ohm.}
\]

Considering the approximation for D, as expressed in 5.11
\[
D = \frac{4(k_0 W)^2}{\eta_0 G_r}
\]
\[
\text{(5.11)}
\]

Where
\[G_r\] is the radiation conductance of the patch. The directive gain
\[G\] of an antenna is defined as
\[
G = \eta_r D
\]
\[
\text{(5.12)}
\]

Where
\[\eta_r\] is the radiation efficiency of the antenna
Gain is always less than directivity, because \(0 < \eta_r < 1\).

5.2.6 Radiated power
Mathematically it is,
\[
P_r = \frac{1}{2\eta_0} \int_0^{\frac{\pi}{2}} \int_0^{2\pi} \left( |E_\theta|^2 + |E_\phi|^2 \right) r^2 \sin(\theta) d\theta d\phi
\]
\[
\text{(5.13)}
\]

Where
η₀ is the radiation efficiency

5.2.7 Stored Energy
Mathematically it is,

\[ W_T = W_e + W_m = \frac{1}{4} \iiint_V \left( \varepsilon |E|^2 + \mu |H|^2 \right) dv \] \hspace{1cm} (5.14)

At resonance these two energies are equal (electric and magnetic). Therefore equation (5.14) can be simplified to equation 5.15,

\[ W_T = \frac{1}{2} h \varepsilon \iint_S |E|^2 ds \] \hspace{1cm} (5.15)

5.2.8 Losses and Quality Factor
The quality factor of a patch antenna needs to be determined to implement the cavity model. It is also useful in determining the VSWR bandwidth of the antenna. The quality factor associated with various types of losses in the patch antenna. We can write

\[ \frac{1}{Q_T} = \frac{1}{Q_d} + \frac{1}{Q_c} + \frac{1}{Q_r} + \frac{1}{Q_{sur}} \] \hspace{1cm} (5.16)

Where
Qₜ represents total quality factor,
Qₓ represents dissipated quality factor
Qₓ represents conducted quality factor
Qₓ represents radiated quality factor
Qₛ represents surface wave quality factor

Q represents any of the quality factors and it is defined as

\[ Q = \frac{\omega_r W_T}{Associated \ power \ losses} \] \hspace{1cm} (5.17)

Where
\[ \omega_r = 2 \pi f \ (f= \text{frequency}) \]
5.2.9 Radiation Efficiency

Mathematically it is,

\[ \eta = \frac{P_r}{P_i} \]  \( \cdots (5.18) \)

The input power gets distributed in the form of radiated power, surface wave power and dissipation in the conductor and dielectric. Therefore it can be expressed as

\[ \eta_r = \frac{P_r}{P_r + P_c + P_d + P_{surr}} \]  \( \cdots (5.19) \)

Where

- \( P_r \) represents radiated power
- \( P_c \) represents conducted power
- \( P_d \) represents dissipated power
- \( P_{surr} \) represents surfacewave power

The dissipated power is generally small for low-loss substrate at microwave frequencies, we can write as

\[ \eta_r = \frac{P_r}{P_r + P_c + P_{surr}} \]  \( \cdots (5.20) \)

Radiation efficiency depends on the substrate thickness and permittivity, and is not affected very much either by the patch shape or by the feed. A numerical result shows that radiation efficiency is almost independent of aspect ratio \( \frac{W}{L} \) of the rectangular patch.

Radiation efficiency affects the directive gain of the antenna through \( G = \eta_r D \).

The gain variation with frequency is almost identical to that of radiation efficiency because directivity is constant with resonant frequency for a given substrate.
5.3 Proposed Antenna models

5.3.1 Design and development of Microstrip Patch Antenna
Steps to implement the stacked microstrip patch antenna

1) Designing the three dimension geometry

![Figure 58 Proposed three dimensional model](image)

Defining the layers:
1) Ground layer (bottom) assigning as a perfect conductor (100mm x 100 mm, copper material)
2) Substrate layer (middle) assigning as a dielectric material (100mm x 100 mm, dielectric constant 2.2, height 3mm)
3) Patch layer (top) assigning as a perfect conductor (23.8mm x 18 mm, copper material)

The dimensions of basic microstrip patch antenna are indicated in figure 59. The patch length and width is calculated from the equation 5.1 and equation 5.2 respectively.
Assigning the coaxial cable excitation technique as shown in figure 60 and defining the wave port at bottom layer indicated in figure 61. Energy is excited from that port. Inner conductor dimension is 1.2 mm and outer conductor dimension is 2 mm. Its length is 4 mm.
After defining excitation to patch geometry desired frequency is set as solution frequency. This is indicating in figure 62. Here it indicates maximum number of passes which represents number of times the tetrahedral meshes are created for minimum error or it is also known as optimum solution. This optimum solution is represented as a Delta S, in my case it is solved up to 0.02.
For the result analysis purpose different sweeps are undertaken such as,

**Discrete** – The accuracy which is provided by this method is highest as it is based on the full solution at each and every frequency specified in sweep. It gives the best result when few frequency points are there to represent the accurate results in the frequency range.

**Interpolative** - It uses to give solution for entire frequency range. It is best suited for the wide frequency range, it results the smooth response.

**Fast** - For quick analysis purpose fast sweep is chosen. It gives the accurate results near to the resonance of model.

Generally fast sweep or discrete sweep is used throughout in this thesis.
Interpolating sweep is selected as shown in figure 63 when detailed analysis of radiation pattern and antenna parameters is required.

Next step is to assign boundary condition to proposed geometry. Its dimensions are generally taken as 4x. So that it covers the front and back hemisphere. The radiation boundary of proposed model is set as shown in figure 64.
As all the above steps are completed, check the design parameters like three dimension model geometry, excitation, boundary condition and analysis for desired frequency. It indicates if any error is present or not as shown in figure 65.

After completing all the necessary steps analyze the geometry by activating the analysis set up as shown in figure 66.
Select the whole geometry and assign Mesh plot. Meshing of the whole geometry is based on the tetrahedral shape; each and every node resultant electric field vector is calculated and from those results is calculated. This calculation is based on the Finite Element Method (FEM). Figures (67, 68, and 69) describe the various views of meshing of the proposed geometry. The close observation of top view and bottom view show that the meshes are very small at the point of excitation where energy is entered in to the patch.
5.3.1.1 Result Discussion

After finishing the CAD drawing and modeling of the patch antenna in HFSS, the parameters are needed to be defined in the software. First of all, I need to set the frequency range over which we want to simulate the geometry. After that, the boundary condition is defined for the entire model. Here, I add the field monitors to examine the electric and magnetic field, current density, power density and energy density. The far-field field monitor is also defined. After completion of parameter definition, the solver can be invoked.
For model design take the frequency sweep from 4 GHz to 7 GHz. This resonant structure is designed to resonate at 5 GHz.

Return loss shows the model is resonate at 5.1 GHz as shown in figure 70. From the return loss plot, I state that the structure resonates at desired frequency. Return loss dip is below -30 dB. It indicates the model designed is correct and has a good impedance match. The resonance can also be measure in Smith Chart, for correct impedance matching curved should pass from the unit circle or desired frequency should be nearer to the unit circle as shown in figure 71.
Voltage Standing Wave Ratio is a measure of impedance matching. For perfect impedance matching VSWR value should be less than 2 is desirable for resonant frequency. Figure 72 indicates VSWR value at 5.1 GHz is 1.02 which is desirable.
Here, gain plot is presented. The patterns are plotted for theta in the range -90 to +90 for phi in XZ plane (0 degree), diagonal plane (45 degree) and YZ plane (90 degree). Gain achieved using this method is about 7.9dB as shown in result figure 73.

The predicted radiation patterns for the proposed antenna geometry show an encouraging result. A directivity of 7.9 dB (figure 74) is achieved which is expected from a single-element patch antenna supporting the fundamental mode of resonance.

Figure 73 Gain plot
Figure 74 Directivity plot

Figure 75 Radiation pattern of proposed model (E plane)
Polar pattern represents the E filed pattern and H filed pattern, which represents the front direction is more and back side radiation is very less (figures, 75 and 76). A front to back ratio of nearly 22 dB is achieved, which is indicating in Co polarization and cross polarization graph as expected from this model (figure 77).

Figure 76 Radiation pattern of proposed model (H plane)
The radiation plot in three dimension is shown in figure 78.
The electric field is plotted in patch geometry from that I can define the radiating edge; it also shows how electric filed distribution takes place in patch (figure 79). Same way magnetic field is also plotted in patch geometry (figure 80).
Surface current density in vector form is plotted in patch. The current vector densities are more at the edge of the patch so radiation takes place from that edge (figure 81). This analysis is required to study the patch behavior at desired frequency.
Fabrication is done to validate the design. Fabrication process involves the etching process of Duroid material sheet, in that duroid substrate is sandwiched between copper materials. The bottom layer is made up of copper layer and it act as a ground plane. So no part is removed from it. But the top layer is patch layer. So according to size and shape of patch etching is done. Next step is to excite the patch layer by means of co axial feed. The center conductor of co axial is soldered with the desired position in patch; the centre conductor is through from ground and dielectric material. In the figures (82 and 83) proposed models top view and bottom view are presented. Measurement setup is shown in figure 84.

The fabricated microstrip patch antenna operates at 5 GHz and there is a good match between the measured (figure 85) and simulated results. The shift in the resonant frequency can be explained by the slight variation in fabrication process, soldering of co axial cable that are sometime contributing causes of the frequency drift. The drift in frequency is 0.1 %.
Figure 83 Fabricated Microstrip Patch Antenna (bottom view)

Figure 84 Measurement setup of Microstrip patch antenna with network analyzer
Figure 85 Measure return loss graph
5.3.2 Stacking of Patch

In this section first I consider the stacked microstrip patch antenna and then the upper patch rotation. I observe the upper patch rotation and found which antenna parameters should be varies. After varying the different parameters and from the analysis of results I have selected the model which gives good bandwidth as well as gain.

To improve the performance of patch antenna stacking phenomena is used [16-18]. With the help of stacking we can improve the antenna parameters. Figure 86 is indicating two layer patch geometry. Lower patch antenna (its dimensions are 23.8mm x 18 mm) is directly connected with the coaxial cable. This excited energy then couples with upper patch (with same dimensions of lower patch) with the help of electromagnetic coupling. The upper patch is separated by lower patch by another dielectric medium (duroid material, dielectric constant 2.2 and height 5 mm). Selection of dielectric medium is so important that it directly affects the antenna parameters. Figure 86 shows the stacked patch model.
The first approach is to understand the behavior of stacked patch and then review the process of patch rotation. Because of stacked patch, slight frequency drift is observed compared to single element patch. This is because of loading effect.

5.3.2.1 Result Discussion

In return loss graph (figure 87) frequency drift is good sign of impedance matching at 5.125 GHz. The same effect is observed in Smith Chart (figure 88) and VSWR graph (figure 89).

Figure 87 Return loss graph (stacked model)
Figure 88 Smith Chart (stacked model)

Figure 89 VSWR graph (stacked model)
From the gain plot, three graphs are plotted. An information for E filed plane (phi=0 degree), second information for H filed plane (phi=90 degree) and for diagonal plane (phi=45 degree). Radiation pattern is symmetrical (figure 90). Directivity is also plotted which shows 8.75 dBi (figure 91).
From the co-polarization and cross-polarization graph, I find better radiation behavior of the antenna and that is a good sign of correlation between co-polarization and cross-polarization, which suggests that this antenna is linearly polarized (figure 92).
Radiation pattern is plotted in polar form which represents electric field at 5 GHz (figure 93). Same way, magnetic field is also represented in polar form (figure 94).
With the help of HFSS, it is possible to view Electric field distribution on patch antenna which is useful to understand the behavior of model (figure 95). Same way Magnetic field is also plotted in patch geometry (figure 96).

For better understanding purpose, surface current vector is also plotted on patch, surface current is more inclined towards length as shown in figure 97.
Figure 98 shows radiation from the stacked geometry. It represents the nature of radiation from patch antenna and gives broad idea of front side and back side radiation.
Figure 98 Radiation from Stacked patch antenna
5.3.3 Stacked Microstrip Patch antenna: Effect of Patch rotation

5.3.3.1 Rotation by 20 degree
Rotating the upper patch and on the basis of simulation results I find the best rotated upper patch position. Gradually rotating the upper patch and observe its effect on simulated results as shown in figure 99 and 100.

Figure 99 Upper patch rotated lower patch remain as it is

Figure 100 20 degree rotation of upper patch
Looking in to simulated results, return loss figure 102 shows frequency in lower side (4.85 GHz), gain plot and co polarization – cross polarization graph still gives good results (figure 103 and 104).

Figure 101 the 20 degree rotation of upper patch (top view)
Figure 102 Return loss graph (the 20 degree rotated upper patch)

Figure 103 Gain plot (the 20 degree rotated upper patch)
The three dimension view of radiation plot is shown in figure 105.
5.3.3.2 Rotation by 45 degree

In this case upper patch is gradually rotated by 45 degree; different views are shown in figure 106 and 107. Its effect on simulated results is observed.
Return loss shown in figure 108 is shifted to 4.67 GHz. Gain parameter is 8.12 dB as shown in figure 109 and figure 110. In the graph of cross polarization and co-polarization as shown in figure 111, cross polarization is slightly increased because of loading effect on lower patch.
Figure 109 Gain plot (the 45 degree rotated upper patch)

Figure 110 Radiation pattern plot (the 45 degree rotated upper patch)
Figure 111 Co-polarization and cross-polarization graph (the 45 degree rotated upper patch)
5.3.3.3 Rotation by 60 degree
In this case upper patch is 60 degree rotated as shown in figure 112 and 113. Return loss graph shown in figure 114 indicates that this structure resonates at two different frequencies 6.32 GHz and 4.78 GHz.
Figure 113 The 60 degree rotation of upper patch (top view)

Figure 114 Return loss graph (the 60 degree rotated upper patch)
Gain is improved up to 1 dB, 8.42 dB is achieved as shown in figure 115. From the co-polarization and cross-polarization graph figure 116 we can observe that both co-polarization and cross-polarization have same level which indicates the circular polarization.
So without changing the shape of patch I achieve the circular polarization. The three dimension graph of radiation pattern is also plotted in figure 117; it represents the amount of power concentrate in one particular direction (red color indicates maximum power intensity while blue color indicates minimum power intensity).

5.3.3.4 Rotation by 90 degree

The proposed model is shown in figure 118 and 119 it represents that upper patch is rotated by 90 degree. Simulation result shows return loss is at 4.5 GHz frequency, as indicated by figure 120. Gain achieved from this model is 8.22 dB (as shown in figure 121). Distance between co polarization and cross polarization is sufficient enough so I can use this patch as a
linear polarization as shown in figure 122. Three dimensional graph of Gain is plotted in figure 123; the shape shows the overall radiation.

Figure 118 the 90 degree rotation of upper patch

Figure 119 the 90 degree rotation of upper patch (top view)
Figure 120 Return loss graph (the 90 degree rotated upper patch)

Figure 121 Gain plot (the 90 degree rotated upper patch)
Figure 122 Co polarization and cross polarization graph (the 90 degree rotated upper patch)

Figure 123 Radiation pattern (the 90 degree rotated upper patch)
5.3.4 Waveguide fed Cavity backed patch radiator

This section represents design, analysis and simulation of cavity coupling modules for three different frequencies.

HFSS is a high performance electromagnetic field simulator which is used for three dimensional geometry, it is also compatible on Microsoft environment.

Systematic approach to design cavity back patch radiators:

Step 1:
Design a rectangular waveguide which allows frequencies from 5 GHz to 10 GHz.
Its dimension is a= 42mm, b= 20mm, length=40 mm its front view and top view is indicating in figure 124.

Figure 124 The three dimension view of waveguide
Step 2:
Design a rectangular slot (its dimensions 23.8 mm x 3.5 mm) at one end of waveguide so as to excite a cylindrical cavity shown in figure 126.
Slot dimension is one of the deciding parameter for resonant frequency. Its front view and top view is indicating in figure 126 and 127.
Figure 126 The slot is etched on circular plate on one end of waveguide

Slot of size 23.8 x 3.5 mm

Figure 127 The slot is etched on circular plate on one end of waveguide (top view)
Step 3:
Design a cylindrical cavity.
A cylindrical cavity (dimensions are height 38mm and diameter 61mm) is required to be excited from a waveguide and an estimate of the coupling level is desired. To enables this a rectangular waveguide with an end wall slot is used to couple energy in from base of the cavity and an identical slot is used to couple it out as in below figure 128, side view of cavity is shown in figure 129.

![Cylindrical cavity design](image.png)

Figure 128 Cylindrical cavity design (lower plate is highlighted)
Step 4:
Design a rectangular slot (23.8mm x 3.5 mm) to other end of cylindrical cavity, which allows an electromagnetic coupling to microstrip patch antenna as shown in figure 130.
Step 5:
Design an elliptical shape (major dimension 40 mm and minor dimension 22 mm) microstrip patch antenna at the top of cavity and precaution is required that patch antenna is exactly placed above the slot so as to allow maximum coupling as shown in figure 131 (elliptical shape patch is highlighted). Aperture coupling helps to improve the bandwidth. Final prepared model is shown in figure 132. Side view and top view is also shown in figure 133 and 134.
Figure 131 Cavity backed aperture coupled elliptical shape patch

Figure 132 The final prepared model
Figure 133 Side view of proposed model

Figure 134 Top view of proposed model
Assigning a radiation boundary to patch radiator:

Radiation boundary is implemented as shown in figure 135. The calculation of near field and far field radiation pattern measurement is possible while radiation boundary is present.

Meshing of the proposed geometry is plotted in figure 136 and 137. The Ansoft HFSS works on finite element methods; it uses tetrahedral meshes at each node. It calculates the resultant electric field. This proposed model dimensions like waveguide, cavity, slot and patch are optimized for X-band.
5.3.4.1 Result Discussion

If we consider the simulated results, return loss is achieved at three different frequencies as shown in figure 138, VSWR plot also claims the same result as shown in figure 139.
Figure 137 Meshing of proposed model (top view)

Figure 138 Return loss graph (waveguide fed cavity backed elliptical patch)
The advantages of cavity backing and waveguide feed are that it provides higher gain and we can use microstrip patch for high power.

The gain of the model is high enough around 10.51 dB as shown in figure 140, directivity graph is slightly broader compared to gain as shown in figure 141.
The graph figure no. 142 shows that the distance between co-polarization and cross-polarization is very high which emphasis that front to back ratio is very good. It also indicates the linear polarization.

Electric field in polar form is plotted (figure 143) which indicates that front side radiation is more as cavity backed patch reduces the back side radiation.
Figure 142 Co polarization and cross polarization plot (waveguide fed cavity backed elliptical patch)

Figure 143 Radiation pattern of E plane (waveguide fed cavity backed elliptical patch)
Magnetic field is plotted in figure 144 in polar form. Plotting the electric field in three dimensions gives an overview of radiation in all directions as shown in figure 145.

The electric field and surface current density in vector form is plotted in elliptical patch antenna as shown in figure.
The magnitude of current density is high at center so maximum radiation takes place maximum from the center of elliptical patch.

Figure 146 Electric field plot on proposed model –top view (waveguide fed cavity backed elliptical patch)
The figure 148 represents how energy enters in to waveguide, then couples to cavity by slot and finally reaches to patch antenna by electromagnetic coupling. As electromagnetic energy reaches to patch antenna it gradually start radiates from the edges of patch. Theses side views (figure 149 and 150) of energy flow shows that how each loop (electromagnetic energy in free space) is detached from the patch.
Figure 148 Radiation from proposed model (xz plane)

Figure 149 Radiation from proposed model (yz plane)
5.3.5 U-slotted microstrip patch antenna

In this section, the design parameters and results for a U-slotted and E-shaped rectangular Microstrip patch antenna in HFSS software are explained and the results obtained from the Simulations are presented. The microstrip patch design is achieved by using probe feed technique. This study is carried out as it provides high gain and broader bandwidth.
The U slotted antenna improves the bandwidth of antenna [6]. The three dimension view is indicating in figure 151. The dimensions are highlighted in the figure 152. The dielectric material is air (dielectric constant 1, height 6mm) as I want the larger bandwidth; the value of dielectric constant should be less.
This geometry is excited by the probe; the results are encouraging for bandwidth purpose.

5.3.5.1 **Result Discussion**

The return loss is below -10 dB from 3.47 GHz to 4.49 GHz as shown in figure 153. This antenna is thin and compact in nature which makes it portable.
The simulated Smith Chart (figure 154) is also good agreement of impedance matching for desired frequency range. A maximum 8.7 dB gain is achieved for 4 GHz (figure 155).
The figure 156 shows that in patch geometry how surface current is distributed, around a U slot the intensity of current is more and away from the slot is gradually reducing.
The electric filed and magnetic field is plotted in patch geometry (figure 157 and 158) which clearly shows a radiating edge of patch, the edges of etched u slot is also contributing in radiation. The radiating edges are representing the longer edges from where electric field distribution is more as shown in figure 157. The electric field and magnetic is always perpendicular in nature so in patch magnetic field component is dominant at non radiating edges as shown in figure 158. Co axial cable is connected near to center and patch is excited by this cable. So maximum energy is at center which gradually moves to surface and from then it starts radiating.

Figure 157 Electric field distribution on patch (U slotted patch)
Assigning the electric field for different planes I find how patch is radiating and also the behavior of this patch when it is excited by coaxial cable. Figures 159,160 and 161 indicate different views of U slotted patch antenna radiation.
Figure 160 Radiation from proposed model (xz plane)

Figure 161 Radiation from proposed model (yz plane)
Figure 162 Fabricated U slotted patch antenna (side view)
The fabrication of proposed model is done. Its side view and top view is presented in figure 162 and 163, as this model is excited by the probe feed technique. It is a kind of stacked configuration because patch layer is separated by the air dielectric material.

![Figure 163 Fabricated U slotted patch antenna (top view)](image)

The measurement is carried out for the validation of the prototype model. The return loss is measured on calibrated vector network analyzer. There is a good agreement of simulated result and fabricated result. As this model is operates for wide band application, it result shows the good impedance matching on that particular band. The measurement setup of U slotted patch antenna with vector network analyzer is as shown in figure 164. The return loss dip is slightly less -21dB compared to simulated result -23 dB as shown in figure 165.
Figure 164 Measurement setup of U Slotted MPA

Figure 165 Measured return loss of U slotted MPA
5.3.6 U slotted E shaped Stacked Microstrip patch antenna

In this portion we are discussing the U slotted E shape stacked microstrip patch antenna (MPA) (figure 166) and its simulated results are discussed. This antenna can be used as a wireless LAN and transceivers. Its three dimension view and top view is presented in figure 167 and 168 respectively.

The proposed antenna is works on S band. The bandwidth enhancement is possible by stacking concept with the help of electromagnetic coupling. The bandwidth enhancement is realized by increasing substrate height but it also excites higher order modes, it increase surface wave which deteriorate overall radiation pattern of microstrip patch antenna.

Here, I have used two substrates. The upper dielectric and lower dielectric material is taken as an air, as it has dielectric constant 1.07. The dimensions of E shape patch antenna are indicated in the figure 169. The design parameters are indicated below:

The lower dielectric constant: 1.07
The upper dielectric constant: 1.07
Upper Dielectric medium: air
Lower Dielectric medium: air
Height of Upper and lower dielectric medium: h1 =6 mm and h2 = 10 mm
Position of feed (x,y): (0 mm,-2 mm)
Figure 166 The proposed U slotted E shaped stacked MPA
Figure 167 The wire frame structure of the proposed model

Figure 168 The top view of the proposed model
5.3.6.1 Result Discussion

The simulated results for this proposed stacked MPA are very encouraging for bandwidth as well as gain.

The return loss graph as shown in figure 170 is achieved from 3.3 to 4.36 GHz; bandwidth achieved is 1GHz (considering -10 dB down result). Almost 26% impedance bandwidth achieved. Same result is reflected in VSWR plot (figure 171). Smith Chart graph figure 172 also shows the impedance characteristics in polar form.
Figure 170 Return loss graph of proposed model

Figure 171 VSWR graph of proposed model
Here I have achieved 8.7 dB gain as shown in figure 173. The graph of co-polarization and cross-polarization is also represented in figure 174, 20 dB separations is achieved from the proposed geometry which is good for the linear polarization. The front to back ratio is 20 dB realized as ground plane removes the back side radiation of the patch.
Figure 173 Gain plot of proposed model

Figure 174 Co-polarization and cross-polarization graph of proposed model
Radiation pattern as shown in figure 175, 176 and 177 is represented in polar and three dimensional form. As observed in polar form side lobe level is so less that almost all the power is radiated in desired direction.

Figure 175 Radiation plot – E plane of proposed model

Figure 176 Radiation plot – H plane of proposed model
Selecting the E shaped upper patch and observes electric field as well as magnetic field distribution (figure 179 and 180). E shaped upper patch is excited by the lower U slot patch antenna which proves the stacking phenomena. This stacked geometry is used to increase the bandwidth of patch antenna. The distribution of electric field is such that it propagates through the radiating edges (as shown in figure 179) and magnetic field is exactly opposite in nature (as shown in figure 180).

The same way selecting the U slotted lower patches and observes the electric field and magnetic field distribution (figure 178 and 181). The electric field plot represents the radiating edges of the patch. U slotted lower patch is a primary source of radiation for the E shaped patch antenna so electric field intensity is more at the radiating edges as compared to the E shaped patch. U slotted patch is excited by the coaxial cable and it is located nearly at center so electric field intensity is more at center area (as shown in figure 178), magnetic field is indicating the non-radiating edges (as shown in figure 181).

To have the broader idea about the antennas radiation its overall radiation is also plotted in different views, see figures 182 and 183. It shows the energy is more at the coaxial cable end.
as red color indicates higher amount of energy. These graphs are more helpful to understand the radiation characteristic of antenna.

Figure 178 Electric field distribution on U slotted patch antenna
Figure 179 The distribution of Electric field on E shape geometry

Figure 180 The distribution of Magnetic field on E shape geometry
Figure 181 Magnetic field distribution on U slotted patch antenna

Figure 182 Emission of radiation from proposed model (xz plane)
Figure 183 Emission of radiation from proposed model (yz plane)

Figure 184 Fabricated U slotted E shape Stacked microstrip patch antenna (side view)
The proposed model is fabricated to validate the design. Its side view and top view is shown in the figures 184 and 185. Its structure is further divided into three stacked layers. The first (bottom) layer is made up of ground layer (copper material, 0.762 mm), the second layer is made up of U slotted patch layer and feed by probe. The final, third layer (top layer, 0.762mm) is made up of E layer (copper material). There are two vacant spaces (air) is there and which act as a dielectric layer. The bottom layer is also indicating in the figure 186.

![Fabricated U slotted E shape Stacked microstrip patch antenna (top view)](image-url)
Figure 186 Fabricated U slotted E shape Stacked microstrip patch antenna (bottom view)

Figure 187 Measurement setup of U slotted E shape Stacked microstrip patch antenna
To validate the simulated result, the measurement is carried out as shown in figure 188. The input reflection coefficient is measured in vector network analyzer as shown in figure 187. The simulated and measured results are similar to each other. The slight distortion in the measured result is because of deviation in size of fabricated model, calibration error and losses in cable.
5.3.7 Pyramidal Horn Antenna
Horn antenna is used for enhancing the gain. First I have analyzed the single horn antenna and then it will be combined to patch geometry [24].

Here waveguide dimensions are selected in such a way that they allow necessary band of frequency. In my case C-band is chosen for design purpose.

The three dimensions proposed waveguide fed horn antenna is shown in different views in figure from 189 to 191. The waveguide length =45.72 mm, width=20.32mm, height=50.8mm, horn height= 152 mm, horn upper rectangle dimensions are 91mm x 71mm as shown in figure 189, top view is also shown in figure 192.

The meshing of proposed geometry is represented in the figure 193. Meshing of the geometry provides the information related to the complexity.
Figure 190 Pyramidal horn antenna (side view)

Figure 191 Horn antenna xz and yz plane
Figure 192 Top view of horn antenna
Figure 193 Meshing of horn antenna

Figure 194 Wave port assignment to waveguide
After designing, my next goal is to excite the horn antenna by waveguide so at one end of waveguide, we will define the wave port and vertically polarized electric field as shown in figure 194.

I have selected the desired frequency as 5 GHz and optimized proposed geometry for minimum error (max delta s = 0.02) as shown in figure 195.

![Figure 195 Solution setup for horn antenna](image-url)
5.3.7.1 Result Discussion

Simulated results of waveguide fed horn antenna shown in figure 196. The return loss graph shows the proposed geometry resonates from 4 GHz to 6 GHz. Basically, it allows the very wide range of frequency.

Smith Chart in figure 197 is also representing that the desired frequency is very close to unit circle.

Figure 196 Return loss graph (horn antenna)
The VSWR plot figure 198 also claims the same result. As it reflects the characteristic of impedance matching, the acceptable range is from 0 to 1.5 in dB for resonance.
From the single horn antenna we can achieve very high gain (13.37 dB) figure 199. Co-polarization and cross polarization graph figure 200 represents the very good front to back ratio.
Figure 199 Gain plot (horn antenna)
Electric field is plotted in polar form which describes the nature of radiation shown in figure 201. Same way magnetic field is also plotted in polar form in given figure 202.
Figure 202 Radiation pattern of H plane

Figure 203 shows three dimensional radiation pattern plot. Major lobe side lobe and back lobe is clearly distinguished in figure 203.

Figure 203 Radiation pattern in three dimension
Magnitude of electric field is plotted in waveguide fed horn antenna shown in figure 204. If we closely observe inner side of waveguide the electric field intensity is more as compared to other surface.

The overall radiation from horn antenna is explained in figure 205. If we consider outer radiation boundary we can have the broader idea about the behavior of horn antenna. It shows the direction of radiation from horn mouth.

Figure 206 and 207 shows radiation from horn antenna in different plane. Both figures explain the radiation of electric field intensity in horizontal and vertical direction.
Figure 205 Emission of radiation from horn antenna (wire frame)

Figure 206 Emission of radiation from horn antenna (xz plane)
Figure 207 Emission of radiation from horn antenna (yz plane)

Figure 208 Fabricated waveguide fed Pyramidal Horn antenna (top view)
The fabrication of pyramidal horn antenna is done. The waveguide is used to feed the high microwave power. The side view and top view is presented in figure 208 and 209 respectively. This antenna is designed for measurement purpose as it has the standard radiation pattern as well as it has high radiation efficiency. Generally for the gain measurement purpose horn antenna considered to be reference antenna.

Figure 209 Fabricated waveguide fed Pyramidal Horn antenna (side view)
The measurement of $S_{11}$ parameter (return loss) is carried out in vector network analyzer as shown in figure 210. As it has the -20 dB down return loss it is best suited for the C band applications. The test result and simulated results are nearly the same. This result also shows that good impedance matching for the desired range of frequencies.
5.3.8 Microstrip patch antenna and Pyramidal Horn Antenna

First I solely analyze the single patch antenna and then we combine the patch and horn antenna and observe its effect on simulated results.

Basic patch geometry is designed shown here in figure 211 and 212 is excited from coaxial cable. The dimensions of microstrip patch antenna are same as mentioned in previous case (figure 59) of basic microstrip patch antenna model. It is designed for 5 GHz frequency.

1) Ground layer (bottom) made up of a perfect conductor (copper material) and its size is 100mm x 100 mm x 0.762 mm,
2) Substrate layer (middle) made up of a dielectric material (dielectric constant 2.2) and its size is 100mm x 100 mm x 3mm,
3) Patch layer (top) made up of a perfect conductor (copper material) and its size is 23.8mm x 18 mm x 0.762 mm,

The dimensions of basic microstrip patch antenna are indicated in figure 59. The patch length and width is calculated from the equation 5.1 and equation 5.2 respectively.
Figure 211 Basic microstrip patch antenna (three dimensional view)
5.3.8.1 Result Discussion

The simulated results can be explained as below.

The return loss graph shown in figure 213 for proposed model is resonates at 5 GHz. Its gain is 8 dB which is very good for single patch antenna as shown in figure 214, three dimensional plot of gain is also presented in figure 215.
Figure 213 Return loss graph (basic microstrip patch antenna)

Figure 214 Gain plot (basic microstrip patch antenna)
Now combine the patch geometry with horn antenna. This proposed model is shown in figure 216, its height is 100 mm. Meshing of the model is shown in figure 217, at patch surface electric field distribution is continuously varying so at that surface tetrahedral meshes are very complex as compared to horn geometry [10]. The dimensions of pyramidal horn antenna are shown in figure 218.
Figure 217: Meshing of proposed model

Figure 218: Dimensions of Pyramidal Horn antenna
Here simulated results are presented. The return loss is shown in figure 219. This model perfectly resonates at 5 GHz. Gain achieved from this model is 12 dB as shown in figure 220. Here the three dimensional radiation plot is also shown in figure 221.

Figure 219 Return loss graph (Horn plus patch antenna)
The overall radiation from this proposed model is shown in figure 222, it provides the information about how electric field distribution in each step. It shows how proposed model is radiating, the formation of radiation loop is visualize by this figure 222.
Figure 222 Emission of radiation (side view)

Figure 223 Fabricated microstrip patch antenna and pyramidal horn (top view)
To validate the proposed model, a fabrication and measurement is done. The top view and side view are presented for prototype geometry (figure 223 and 224). As this model is design for improvement of gain and which can be possible by adding the pyramidal shape horn antenna. There are lot of precautions are required for fabricating the pyramidal horn antenna.

Figure 224 Fabricated Micro strip patch antenna and pyramidal horn antenna (side view)
Figure 225 Measured Setup of Micro strip patch antenna and pyramidal horn antenna

Figure 226 Measured Return loss of Micro strip patch antenna and pyramidal horn antenna
Measurement is carried out in calibrated vector network analyzer as shown in figure 225. The proposed model is resonates on 5 GHz, from the measured result, the fabricated model is resonates on 4.96 GHz as shown in figure 226.

So there is a slight deviation from the simulated result and the return loss is slightly degraded from -27 dB to -23 dB, which is expected from the fabricated model.
5.3.9 Conical Horn Antenna
Conical horn is another kind of horn antenna I have considered for this research.

The conical horn antenna is designed for 5 GHz frequency. Its different view and meshing are shown in figures 227 and 228. Here assignment of wave port is highlighted in the figure 229.
Figure 228 Meshing of conical horn antenna

Figure 229 Wave port assignment of conical horn antenna
The conical horn antenna is fed by circular waveguide. The port excitation is done at one end of waveguide in the antenna [24]. The dimensions of conical horn antenna are shown in above figure 230; its height is 120 mm shown in figure 227.

5.3.9.1 Result Discussion

Simulated results are presented.

Return loss graph indicates that the presented model perfectly radiates at 5 GHz (shown in figure 231). Simulated gain shows very good results (17 dB) for the different values of phi that is for 0 degree, 90 degree and 45 degree (figure 232).
Figure 231 Return loss graph (conical horn antenna)

Figure 232 Gain plot (conical horn antenna)
Co-polarization and cross-polarization are shown in figure 233 at the same level which represents the circular polarization.

The radiation pattern in polar form and in three dimensions is shown in figure 234 and 235. E-plane graph is useful to analyze the electric field intensity in specific direction, from the figure 234 front to back ratio is 27 dB which shows the proposed model is directive antenna.
Figure 234 Radiation pattern E plane (conical horn antenna)

Figure 235 Radiation pattern three dimension (conical horn antenna)
The emission of electric field from conical horn antenna is shown in figure 236, which represents how overall radiation from conical horn antenna is possible. The electric field plot on conical horn antenna is also shown in figure 237.
The fabrication of conical horn antenna is presented (figure 238 and 239). It resonates on C band. The accuracy is required to fabricate the conical shape.
Using the vector network analyzer the return loss is measured (figure 240). It is observed that all the $S_{11}$ responses were measured to be lower than -20 dB, indicating a good impedance match, so there is a similar results observed in measured results as compared to simulated result.
5.3.10 Microstrip patch antenna and Conical Horn Antenna

Combine the geometry (conical horn) with patch antenna, improves the gain parameter of the patch antenna [28]. The dimensions of this prototype model is same as used in previous case of basic microstrip patch antenna model and conical horn antenna model respectively. Proposed model is shown in figure 241.

![Figure 241 Proposed conical horn antenna and basic microstrip patch antenna](image)

5.3.10.1 Result Discussion

Simulated results endorse desired results.

Return loss from this model is achieved at 5 GHz frequency as shown in figure 242. Here the gain is achieved very high-around 16.5 dB as shown in figure 243.
Figure 242 Return loss graph (conical horn plus patch antenna)
Figure 243 Gain plot (conical horn plus patch antenna)
The linearly polarized patch antennas behavior remains constant in terms of polarization while combined with conical horn antenna. (See figure 244 co polarization and cross polarization).

Radiation is represented in polar form as well as in three dimension view in the figure 245, 246 and 247 respectively. Electric field pattern shows the main radiation, it also indicates the concentration of power is more in major lobe as compared to minor lobe. In magnetic field pattern number of side lobes are more so power is distributed more in side lobes.
Figure 245 Radiation pattern E plane (conical horn plus patch antenna)

Figure 246 Radiation pattern H plane (conical horn plus patch antenna)
The overall radiation is represented in figure 248. It shows the energy propagation in various stages like: first it enters through the coaxial cable then it excites the microstrip patch antenna then finally radiation of energy is guided through the horn antenna.
The fabrication and measurement is carried out to validate the prototype design. The conical horn antenna is placed above the patch antenna to improve the gain parameter, its side and top view is presented in figures 249 and 250.
Figure 251 Measurement Setup of Microstrip patch antenna and Conical Horn antenna

Figure 252 Measured Return loss of Microstrip patch antenna and Conical Horn antenna
The return loss of proposed prototype model is measured using a calibrated vector network analyzer (shown in figure 251) and the measurement result is presented in figure 252. The observation of measured result shows that there is a slight deviation in the resonant frequency. It is very difficult to achieve sharp resonance from fabricated model. The fabricated model resonates on 5.13 GHz instead of 5 GHz and the return loss is slightly degraded from -27dB to -23 dB.
In this section we are discussing the effect of horn antenna on E shaped U slotted stacked microstrip patch antenna (MPA).

The basic model of E shaped U slotted stacked MPA is presented in figure 253 [6]. The dimensions of this model are same as in the previous case of U slotted E shape stacked patch antenna and conical horn antenna respectively. Earlier we have discussed its design analysis and simulated results.

To increase the gain parameter, this model is combined with conical horn antenna. Its different views are presented in figures 254 and 255.
Figure 254 Proposed conical horn plus stacked patch antenna

Figure 255 Proposed conical horn plus stacked patch antenna (top view)
5.3.11.1 Result Discussion

The simulated results for this MPA are very encouraging for bandwidth as well as gain.

The return loss graph (figure 256) is achieved at 1.22 GHz bandwidth. Same results are also reflected in VSWR (figure 257) which also measures impedance matching.

Figure 256 Return loss graph (conical horn plus stacked patch antenna)
Smith chart is shown in figure 258, it shows the graph encloses unit circle in a single loop. These loop frequencies are from 3.4 GHz to 4.4 GHz. It shows that band of frequencies are resonates from the proposed geometry.
Figure 258 Smith Chart (conical horn plus stacked patch antenna)

Figure 259 Gain plot (conical horn plus stacked patch antenna)
Here we have achieved 11.62 dB gain shown in figure 259. The graph of co polarization and cross polarization as shown in figure 260 is slightly degraded because stacked geometry generates the linear polarization while conical horn antenna generates the circular polarization and another cause for this is spurious surface wave as we combine patch with conical horn antenna.

Radiation pattern is represented in polar form as shown in figure 261 and three dimension form as shown in 262. Figure 261 presents the polar graph of E plane, H plane and Diagonal plane. As discussed earlier spurious surface wave is disturb the radiation pattern in lower hemisphere as shown in figure 262.

Its overall radiation is also highlighted in figure 263. It gives the complete flow of radiation energy starting from coaxial cable to free space wave. The location of stacked E shaped patch is deviate from the center because of that the radiation energy is more intent in one direction as compared to other direction.
Figure 261 Radiation pattern of E plane (0 degree), H plane (90 degree) and Diagonal plane (45 degree) (conical horn plus stacked patch antenna)

Figure 262 Radiation pattern in three dimensional (conical horn plus stacked patch antenna)
Figure 263 Emission of radiation from proposed model

Figure 264 Fabricated U slotted E shape stacked microstrip patch antenna and conical shape horn antenna (top view)
To validate the proposed design, a proposed geometry is fabricated as shown in figure 264 and 265. Its top view and side view is presented. The conical horn antenna is placed above the U slotted stacked E shaped microstrip patch antenna. The fabrication of conical horn antenna requires more amount of fabrication knowledge.
Figure 266 Measurement Setup of U slotted E shape stacked microstrip patch antenna and conical shape horn antenna

Figure 267 Measured Return loss of U slotted E shape stacked microstrip patch antenna and conical shape horn antenna
With the help of calibrated vector network analyzer (measurement setup is presented in figure 266), the return loss is observed and is presented in figure 267.

The difference in the resonant frequencies can be explained by the variations of and deviations caused during the fabrication process. Slightly deviation in frequency is 3.5 GHz to 3.57 GHz and 4.15 GHz to 4 GHz. So the error is nearly 0.06 % which is valid for the design.
5.3.12 Shi (ψ) shaped Stacked Microstrip patch antenna

In this section I would discuss the Shi shaped (ψ) stacked microstrip patch antenna (MPA) and its simulated results. The basic model of Shi shaped (ψ) stacked MPA is presented in figure 268. Its three dimension view and top view is presented (see figure 268,269 and 270).

Earlier we have discussed the simple microstrip patch antenna then we switched to the stacking phenomena then observed the effect of upper patch rotation. As we know to improve the bandwidth stacking is necessary, further improvement of bandwidth is possible by implementing the Shi shape in patch design [34].

![Figure 268 Proposed shi shaped stacked patch geometry](image)

The dimensions are indicated in figure 269. This stacking geometry uses two substrates, the lower substrate is made up of air (height 5mm) and upper substrate is made up of duroid material (height 1mm), using these two different materials and Shi shaped (ψ) patch large bandwidth is achieved.

The coaxial feed location is shown in figure 270, it is shifted to (7, 7) mm position with respect to center to achieve the perfect impedance matching.
Figure 269 Dimensions of Shi shape stacked MPA

Figure 270 Feeding position with respect to centre
The meshing of the model is presented in figure 271 and 272 so that I can have the broader idea about the complexity of design.

**5.3.12.1 Result Discussion**

The simulated results for this Shi shaped (ψ) stacked MPA are very encouraging for bandwidth as well as gain.
The return loss graph figure 273 shows 3 GHz bandwidth (considering -10 dB down result) is achieved from proposed model. Enormous impedance bandwidth (figure 273) is achieved from this shape.

Same result is also measured in Smith Chart (figure 274); this graph shows the circular spline which indicates that the structure resonates for mainly three different frequencies which are very nearer to each other. The circle which is passing from the unit circle is having 4.5 GHz frequency as shown in figure 274, the other two circles resonates at two different frequencies.
Figure 273 Return loss graph of proposed model

Bandwidth = 3 GHz

Figure 274 Smith Chart of proposed model
Here we have achieved 10 dB gain (figure 275) and same results is also reflected in directivity (figure 276). The graph of co polarization and cross polarization (figure 277) is also represented, 20 dB separations is achieved from the proposed geometry which is good for the linear polarization.
Radiation pattern is represented in polar and three dimension form (figure 278, 279 and 280). As observed in polar form side lobe level is so less that almost all the power is radiated in desired direction.
Figure 279 Radiation pattern of H plane of proposed model

Figure 280 Radiation pattern in three dimension of proposed model
The electric field and magnetic field is plotted in patch (figure 281 and 282). The electric field plot represents the radiating edges of the patch; it also shows the center conductor which is connected to the coaxial cable and it is main source of radiation. The center conductor strip excites the two square geometries. Magnetic field plot is almost zero except for the center strip as shown in figure 282.

Its overall radiation is also plotted in different views (figure 283, 284 and 285). Figure 284 shows how radiation loop is forming from the Shi shaped ($\psi$) stacked microstrip patch antenna. The three dimensional emission of radiation from proposed structure is shown in figure 285.
Figure 282 Magnetic field plot in Shi shaped geometry

Figure 283 Emission of radiation from proposed model (xz plane)
Figure 284 Emission of radiation from proposed model (yz plane)

Figure 285 Overall radiation in three dimension view
The fabrication of prototype model is presented (figure 286 and 287), which is excited by coaxial cable. As it resonates for wide band the fabrication precaution is necessary. The stacked configuration is established by lower substrate and upper substrate. There is an air gap between the substrate of patch and ground plane, as we know the air having dielectric constant 1. So this will help to improve the bandwidth of Shi (ψ) shaped stacked microstrip patch antenna.
Figure 287 Fabricated Shi shape stacked microstrip patch antenna (side view)

Figure 288 Measurement Setup of Shi shape stacked microstrip patch antenna
The measurement setup is shown in figure 288. The fabricated Shi (ψ) shaped stacked microstrip patch antenna operates from 4.2 GHz to 7.2 GHz and measured results and simulated results compliments each other for similarity (figure 289). The slight difference in the measured results can be explained by the variations of and deviations caused during the fabrication process.
5.3.13 Shi Shaped Stacked MPA and Pyramidal Horn Antenna
In this section, the Shi shaped ($\psi$) stacked microstrip patch antenna (MPA), effect of pyramidal horn antennas on it and its simulated results are discussed. Its three dimension view, side view and top view is presented (figure 290,291 and 292). The basic model of Shi shaped ($\psi$) stacked microstrip patch antenna is presented in previous section (see figure 268 and 269).

Here I have used two substrates. The lower substrate is made up of foam material and upper substrate is made up of duroid material. The pyramidal horn antenna is constructed by perfect conductor [10].

![Figure 290 Proposed Shi shaped stacked MPA and Pyramidal horn antenna](image)

This proposed prototype model is combination of two different geometries which is proposed and presented in previous sections. The dimensions are also same as in the above mentioned cases respectively.
Figure 291 Proposed Shi shaped stacked MPA and Pyramidal horn antenna (top view)

Figure 292 Proposed Shi shaped stacked MPA and Pyramidal horn antenna (side view)
5.3.13.1 Result Discussion

The simulated results for this Shi shaped (ψ) stacked MPA and pyramidal horn are very encouraging for bandwidth as well as gain. The gain parameter is further improved by pyramidal horn antenna.

The return loss graph figure 293 shows 3 GHz bandwidth (considering -10 dB down result) is achieved from proposed model. Enormous impedance bandwidth is achieved from this shape (figure 293). Same result is also measured in Smith Chart (figure 294); this graph shows the circular spline which indicates that the structure resonates for mainly three different frequencies which are very nearer to each other.
Here we have achieved 15 dB gain (figure 295) and same result is also reflected in directivity (figure 296). The graph of co polarization and cross polarization is represented in figure 293. In previous section of Shi shape stacked MPA, co polarization and cross polarization difference is 20 dB (figure 277) while in this proposed model it is 13 dB, degradation is occur because of pyramidal horn antenna as this shape having sharp corners. The other source of distortion is spurious surface wave which couples to the horn antenna.
Figure 295 Gain plot (Shi shaped stacked MPA + Pyramidal horn antenna)

Figure 296 Directivity plot (Shi shaped stacked MPA + Pyramidal horn antenna)
Radiation pattern is represented in polar and three dimension form (figure 297, 298 and 300). As observed in polar form side lobe level is so less that almost all the power is radiated in desired direction as shown in figure 297. The H field pattern shows the front to back ratio is almost 24 dB which shows the proposed model is highly directive as shown in figure 298. Three dimension plot shows the combination of E field plot and H field plot.
Figure 298 Radiation pattern of H plane (Shi shaped stacked MPA + Pyramidal horn antenna)

Figure 299 Co polarization and cross polarization graph (Shi shaped stacked MPA + Pyramidal horn antenna)
The electric field is plotted in patch. Electric field plot shows the maximum field intensity at center conductor and edges of the adjacent square geometry and also electric field plot represents the radiating edges of the patch (figure 301). Its overall radiation is also plotted in different views (figure 302, 303, 304 and 305). Figure 302 shows the radiation loop formation and also shows how each loop is detached from the antenna, figure 303 shows the other view of radiation. It shows the maximum energy is first concentrated at coaxial cable then at each stage how electric field is distributed is shown in figure 303. The three dimensional view is shown in figure 304 (combining the information of two plane). The same radiation plot is presented in cloud form as shown in figure 305, in that red color shows the maximum radiation intensity. Pyramidal horn antenna thus concentrates the energy in specified direction.
Figure 301 Electric field distribution in Shi shaped stacked microstrip patch antenna

Figure 302 Emission of radiation from Shi shaped stacked MPA + Pyramidal horn antenna (yz plane)
Figure 303 Emission of radiation from Shi shaped stacked MPA + Pyramidal horn antenna (xz plane)
Figure 304 Overall radiation in three dimensional view from Shi shaped stacked MPA + pyramidal horn antenna.

Figure 305 Overall radiation from Shi shaped stacked MPA + pyramidal horn antenna (cloud form).
The fabrication of proposed geometry is presented in above figure 306. To improve the gain of Shi (ψ) shaped stacked geometry, a pyramidal horn antenna is placed above it. Now because of this pyramidal horn antenna the overall size of the antenna is increases. So there is a tradeoff between size of the antenna and its gain. The size of pyramidal horn antenna is so chosen that it does not much affect the size and weight of the Shi (ψ) shaped stacked geometry.
The top view and side of the proposed geometry is shown in figures 306 and 307. The precaution is required to fabricate the geometry as it works on microwave frequencies.
Figure 308 Measurement Setup of Shi shaped stacked microstrip patch antenna and pyramidal horn antenna

Figure 309 Measured return loss of proposed model
To validate the design a measurement is carried out as shown in figure 308. The return loss of this antenna is measured and the results are presented in figure 309. The measured results are quite similar to simulated result. Here slight variation at 7 GHz frequency, which can be cause of calibration error of vector network analyzer as this effect was not included in simulated results.