Chapter 4 Materials and Methodology

This chapter presents the materials which are used to design Microstrip patch antenna (MPA), cavity backed MPA, Stacked MPA. This chapter also describes the tool which is used to design, simulate and generates the results according proposed model. In the later portion of chapter different methods are explained to obtain antenna results like return loss, impedance bandwidth, gain, directivity, vswr, radiation pattern in two dimensional as well as three dimension.

4.1 Selection procedure of substrate

The selection of substrate is again very vital in microstrip patch antenna design, as it should satisfy the electrical and mechanical properties of desired antenna requirements. In selection of substrate, dielectric constant is one of the important parameter of design. Depending upon the requirement, different dielectric constant is chosen; a low dielectric constant may be used to improve the efficiency and bandwidth. A low dielectric constant has low Q and because of that it provides high bandwidth. It also generates greater amount of fringing field at the patch geometry. The patch also generates the surface wave which is excited by fringing filed and different feeding techniques.

A substrate which is having low dielectric constant has low surface wave because of that less amount of power loss.

In the prototype model design RT/duroid 5880 was used. This composite material has a 2.2 dielectric constant, it is easily available in market. The fabrication on this material with printed circuit technology is easy, this material is mechanically robust.

The foam material has also low dielectric constant which is 1. In one of the prototype model foam material is used.

For practical approach we can also consider air as a dielectric material. The large bandwidth can be made possible by introducing various low dielectric materials for one configuration of microstrip patch antenna.

In selection of dielectric material a small value of loss tangent is desirable, to reduce the dielectric medium loss.
Thickness of substrate is another important aspect of design. It provides mechanically robust structure, as it’s having lower Q, which gives higher bandwidth. It is also having some disadvantages like increment in weight, dielectric loss and surface wave, because of probe feed spurious radiation may takes place. In this thesis depending upon the requirement substrate thickness is chosen like 3mm, 6 mm, 10 mm etc.

4.2 Operating system
To operate the simulator minimum requirement is 4 GB of RAM. According to design simulation time is decided. As virtual simulator is operated on finite element method it defines geometry on meshes based and analysed according to passes. So this whole process requires high calculation and high speed processor.

The processor should be fast enough to give results as per the requirement of simulation tool. A minimum requirement of processor is CORE i-3 or high version of it. If processor speed is not high enough then because of lack of computing speed simulation tool may abruptly closed or abruptly hang for the desired simulation.

4.3 Simulation tool (HFSS)
The antenna analysis for this thesis was carried out using the Ansoft HFSS. This software is based on Finite Element Method (FEM) [30]. In this technique, the complete geometry is divided into thousands of smaller segments.

The small segments indicate the field and this field can be represented by mathematical function. The software uses FEM to compute the geometry, this geometry is again subdivided in to tetrahedral meshes.

The single tetrahedral constructs from four triangles. Depending upon the tetrahedral meshes software calculates the field component. With the help of derived field quantities, Maxwell’s equations can be easily solved by matrix equations.
Above figure 38 represent how this virtual simulator works. It also shows the different steps to solve the geometry. There is always trade-off between accuracy and time.

Mainly accuracy is depends on small size of individual elements so solution which is based on large amount of individual elements are more accurate. Simultaneously large amount of small meshes requires high processing speed and large computer memory. It is desirable to choose accurate field but not so fine enough which consumes processing speed and time.

Basically HFSS uses an iterative process to compute critical regions. In first step it generates the solution based on initial mesh then it refines the mesh as per the error criteria. In the first step it divides the geometry and generates the solution which is based on the initial mesh then it will refines the mesh according to error. This limit is defined as delta error, in this thesis this delta error is chosen as 0.02 [10].
To design any model in HFSS it requires certain steps. In the first step geometry is design in three dimension view. Then materials are assigned to respective geometry. For providing ground perfect E boundary is chosen. In the next step excitation is given by means of wave port or lumped port. Based on this desired analysis set up is done, which is for desired frequency range.

Now to observe the results different results are obtained, to get far field results a boundary known as a radiation is set for the desired geometry.

### 4.4 Methodology

#### Basic Antenna Parameters

There are some parameters which are related with the designing of Antennas. They are discussed in the following sections.

#### 4.4.1 Reflection Coefficient ($\Gamma$) and Characteristics Impedance ($Z_0$)

The reflection is always present in the high frequency applications, which occurs in microwave transmission lines. It is the ratio of by normalizing the amplitude of the reflected voltage $V_0^-$ to the amplitude of the incident wave $V_0^+$ and it is given in equation 4.1

$$\Gamma = \frac{V_0^-}{V_0^+} \quad \text{(4.1)}$$

In every transmission line basic impedance is correlated because of its material characteristic this basic impedance is known as characteristic impedance ($Z_0$), now this transmission line is always terminates with some load. This load having some impedance it is known as load impedance. Now when characteristic impedance of transmission line doesn't match with load impedance a reflection takes place.

The reflection coefficient can be defined in terms of characteristic impedance and load impedance as equation 4.2

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \quad \text{...(4.2)}$$

#### 4.4.2 Return Loss

It is a measurement of how much amount of power is reflected from the load. The reflected radio waves cause the standing wave pattern.
So this return loss (RL) also measures matching between antenna and transmitter impedance same as in the case of VSWR. The return loss can be given in equation 4.3

\[
RL = -20 \log |\Gamma| \text{ (dB)} \quad \text{...(4.3)}
\]

To have the exact matching between antenna and transmitter, return loss should be infinite. It indicates that no power is reflected. The acceptable range of VSWR is two and in terms of mathematical representation is given by the return loss value -9.54 dB

### 4.4.3 Impedance matching

Now the input impedance can be describe as impedance presents at antenna terminals. Impedance of the antenna is written as:

\[
Z_{\text{in}} = R_{\text{in}} + j X_{\text{in}} \quad \text{...(4.4)}
\]

Where:  
- \(Z_{\text{in}}\) represents input impedance  
- \(R_{\text{in}}\) represents antenna terminal resistance  
- \(X_{\text{in}}\) represents antenna terminal rectance
In above equation, imaginary part represents the amount of energy which is stored in the antennas near field. Whereas real quantity, resistance can be further divided into two parts. The first part is related to the radiation resistance which represents the total emission of power by the antenna. The second part is related to the loss resistance which indicates antenna loss because of different parameters like heat, dielectric and conduction loss.

### 4.4.4 Radiation Pattern

It is defined as the graphical representation of antennas properties like gain, power, beam width this all quantities measured with respect to angles. The figure 40 shows the antenna radiation patterns with its parameters.

![Radiation Pattern 1](image)

**Figure 40 Radiation pattern**

### 4.4.5 Gain
With the help of power gain and directive property of the antenna we can have the broader idea about the antennas radiation in specified directions.

The antennas gain can be defined as a ratio of power emitted to the power accepted by the antenna. Mathematically, gain as expressed in equation 4.5

$$G = \frac{4\pi U(\theta,\phi)}{P_{in}}$$

Where $P_{in}$ = power radiation of lossless isotropic source

$U(\theta, \phi) =$ radiation intensity of the antenna under test

![Figure 41 Gain plot (2 D view)](image-url)
The gain of the antenna also gives the broader view of antennas directional property (figure 41), which relates with how power is concentrate in narrow region. The three dimension antenna gain is also plotted in figure 42.

### 4.4.6 Voltage Standing Wave Ratio (VSWR)

When the condition of matching is not satisfied, that means, \( Z_L \) in not equal to \( Z_0 \), then the power is reflected back and it corresponds to the creation of standing waves. The standing wave can be defined in terms of Voltage Standing Wave Ratio. VSWR as in equation 4.6,

\[
VSWR = \frac{V_{\text{max}}}{V_{\text{min}}} = \frac{1+|\Gamma|}{1-|\Gamma|} = \frac{1+S_{11}}{1-S_{11}} \quad \text{...(4.6)}
\]
The VSWR graph as shown in figure 43 represents the impedance matching between antenna and transmission line. If its value is 1:1, it represents the perfect matching between antenna and transmission line. In addition, for an antenna to be reasonably functional, a maximum value of VSWR can be considered as 1.5 generally.

### 4.4.7 Smith Chart

This chart is the representation of reflectoin coefficient $\Gamma$ in polar form. The amount of power reflected back depends upon the degree of mismatch between the load and the source impedance.
The circles shown in figure 44 are lines of constant resistance, where as the small circle to the right is the circle of infinite resistance. The curves crossing the circles are lines of constant reactance, with the horizontal line as zero.
The best results are obtained when the line of reactance crossed the circle of unity resistance (as indicated in figure 45), where exact impedance matching is done. The distance from the loop to the centre of the Smith Chart indicates the value of the reflection coefficient.

4.4.8 Bandwidth

It is defined as the range of frequency over which antennas certain parameter remain constant or follows the specific standards. Antennas parameter like polarization, side lobe level, gain, directivity and radiation pattern are above the specified level or full fill the certain requirements with respect to centre frequency. The bandwidth is also defined in terms of impedance, that case how much amount of power is reflected back is observed with respect to center frequency. The figure 46 indicates the Impedance bandwidth.

Figure 46 Impedance Bandwidth
Sometime bandwidth can also be represented in terms of percentage (narrow band operation), it calculated as the ratio of difference between higher frequency and lower frequency to the center frequency. It also represents the ratio of upper to lower frequencies. Considering one example, 5:1 indicates the upper frequency is 5 times greater than the lower frequency. In mathematical form, the bandwidth can be expressed as in equation 4.7 and 4.8,

\[ \text{BW}_{\text{broadband}} = \frac{f_H}{f_L} \] \hspace{2cm} ...(4.7)

\[ \text{BW}_{\text{narrowband}}(\%) = \frac{f_H - f_L}{f_L} \times 100 \] \hspace{2cm} ...(4.8)

### 4.4.9 Directivity

Directivity is defined as the ratio of maximum radiation intensity to the average radiation intensity. Mathematically it is expressed as in equation 4.9,

\[ D_{\text{max}} = \frac{U_{\text{max}}}{U_{\text{avg}}} \] \hspace{2cm} ...(4.9)

Where

- \( D_{\text{max}} \) represents the maximum directivity of the antenna
- \( U_{\text{max}} \) represents the maximum radiation intensity
- \( U_{\text{avg}} \) represents the average radiation intensity
Figure 47 Directivity graph

Since directivity is expressed as the ratio of two same nature quantities (radiation intensities). It is dimensionless and represented in dBi where i represents decibel is measured with respect to isotropic source. Directivity is inversely proportional to the beam area, if beam area is narrow than directivity is high. Two dimensional directivity graph is shown in figure 47.

4.4.10 Polarization

It defined as the time varying behaviour of magnitude of electric field vector. Polarization can be represents as the graphical representation of loci of the tip of electric field vector. The below figure indicates the polarization figure 48 and figure 49.

As shown in figure 48 linearly polarised wave is varying with respect to time. It only varies in vertical direction so it is known as vertical polarised signal. The circularly polarised wave is presented in figure 49. The electric field vector is present in X direction as well as in Y direction.
The magnitude of X direction vector and Y direction vector is same and if it is not same then that polarisation is known as elliptical polarisation.

Figure 48 Linear polarization (Vertical direction)

Figure 49 Rotation of plane electromagnetic waves
Now considering the above figure 50 the polarization is again subdivide into the main three subtypes. In the first type, the electric field vector is present only in one direction, either horizontal or vertical.

In the second type, the electric field vector is present in both directions; its magnitude is constant but it rotates around in a circular path. Further, the directions of rotations are again divided into two types: right-hand circular polarization rotates around the clockwise direction, and if it rotates in the anti-clockwise direction, it is known as left-hand circular polarization. As indicated in figure 51.
Figure 51 Different Polarization