Design of Hexagonal Microstrip Antenna for S-Band Applications

A project work submitted in partial fulfilment of the requirements

for the award of degree of

Bachelor of Technology

in

Electronics and Communication Engineering

by

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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, ease of fabrication and smaller in dimension. Microstrip patch antennas are becoming increasingly useful because they can be printed directly onto a circuit board. Most commonly used microstrip patch antenna shapes are rectangular and circular. Recently due to advancement in the field of computer aided antenna design and simulation, microstrip antenna of other shapes are analyzed. Hexagonal shape of microstrip antenna is one of the promising shapes to be used because of increased bandwidth, parasitic coupling and two feeding positions.

In this project, a hexagonal shaped microstrip patch antenna is designed for S-band application using FR-4 epoxy (Flame Retardant) substrate with a thickness of 1.6mm. Microstrip line feeding technique is used to achieve impedance matching at the desired frequency. Important parameters such as return loss, gain, radiation pattern, current distribution and radiation efficiency are observed using Ansoft HFSS simulation tool to measure the performance of the antenna in the given band.

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CHAPTER 1

INTRODUCTION TO ANTENNAS

An antenna is a device that is used to convert guided electromagnetic waves into electrical signals and vice versa (i.e. either in transmitting mode or in receiving mode of operation). Antennas are frequency dependent devices. Each antenna is designed for a certain frequency band and outside of this band, antenna rejects the signal. Therefore, antenna is a band pass filter and transducer. Antennas are essential part in communication systems therefore understanding their basics are important.

With the advances in telecommunication, the requirement for compact antenna has increased significantly. In mobile communication, the requirement for smaller antennas is quite large, so significant developments are carried out to design compact, minimal weight, low profile antennas for both academic and industrial communities of telecommunication. The technologist focused into the design of Microstrip patch antennas. Many varieties in designing are possible with Microstrip antenna.

How an Antenna radiates? In order to know how an antenna radiates, let us first consider how radiation occurs. A conducting wire radiates mainly because of time-varying current or an acceleration (or decelerations) of charge. If there is no motion of charges in a wire, no radiation takes place, since no flow of current occurs. Radiation will not occur even if charges are moving with uniform velocity along a straight wire. However, charges moving with uniform velocity along a curved or bent wire will produce radiation. If the charge is oscillating with time, then radiation occurs even along a straight wire. The radiation from an antenna can be explained with the help of Figure 1.1 which shows a voltage source connected to a two conductor transmission line. When a sinusoidal voltage is applied across the transmission line, an electric field is created which is sinusoidal in nature and these results in the creation of electric lines of force which are tangential to the electric field. The magnitude of the electric field is indicated by the bunching of the electric lines of force. The free electrons on the conductors are forcibly displaced by the electric lines of force and the movement of these charges causes the flow of current which in turn leads to the creation of a magnetic field.

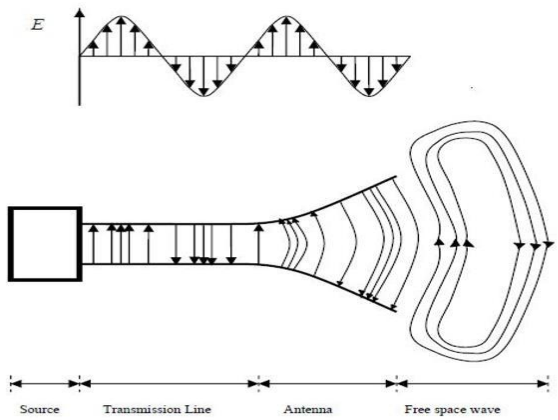

Fig 1.1: Radiation from an antenna

Due to the time varying electric and magnetic fields, electromagnetic waves are created and these travel between the conductors. As these waves approach open space, free space waves are formed by connecting the open ends of the electric lines. Since the sinusoidal source continuously creates the electric disturbance, electromagnetic waves are created continuously and these travel through the transmission line, through the antenna and are radiated into the free space. Inside the transmission line and the antenna, the electromagnetic waves are sustained due to the charges, but as soon as they enter the free space, they form closed loops and are radiated.

Near and Far Field Regions The field patterns, associated with an antenna, change with distance and are associated with two types of energy: - radiating energy and reactive energy. Hence, the space surrounding an antenna can be divided into three regions.

1.1. TYPES OF ANTENNAS

There are two fundamental types of antenna directional patterns, with reference to a specific two dimensional plane (usually horizontal [parallel to the ground] or [vertical perpendicular to the ground]), are either:

1. Omni-directional (radiates equally in all directions)
2. Directional (radiates more in one direction than in the other).

In colloquial usage "omnidirectional" usually refers to all horizontal directions with reception above and below the antenna being reduced in favor of better reception near the horizon. A directional antenna usually refers to one focusing a narrow beam in a single specific direction such as a telescope or satellite dish, or, at least, focusing in a sector such as a 120° horizontal fan pattern in the case of a panel antenna at a cell site.

The present antenna in the thesis i.e., Microstrip antenna is an omnidirectional antenna which radiates normal to the patch surface into the upper hemisphere (180° in elevation plane) and 360° in azimuth plane. There are many variations of antennas. Below are a few basic models:

- The **isotropic radiator** is a purely theoretical antenna that radiates equally in all directions. It is considered to be a point in space with no dimensions and no mass. Most antennas' gains are measured with reference to an isotropic radiator, and are rated in dBi (decibels with respect to an isotropic radiator).

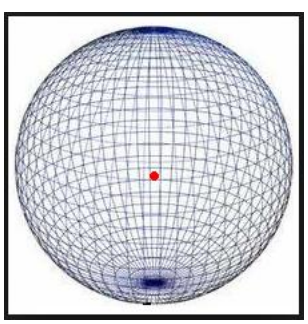

Fig 1.2: Isotropic antenna

- The **dipole antenna** is simply two wires pointed in opposite directions arranged either horizontally or vertically, with one end of each wire connected to the radio and the other end hanging free in space. Since this is the simplest practical antenna, it is also used as a reference model for other antennas; gain with respect to a dipole is labeled as dBd.

Fig 1.3: Dipole Antenna

- The **wire antenna** is simply a very long (at least one quarter wavelength) wire with one end connected to the radio and the other in free space, arranged in any way most convenient for the space available. Folding will reduce effectiveness and make theoretical analysis extremely difficult.

Fig 1.4: Wire Antenna

- The **horn** is used where high gain is needed, the wavelength is short (microwave) and space is not an issue. Horns can be narrowband or wideband, depending on their shape. A horn can be built for any frequency, but horns for lower frequencies are typically impractical. Horns are also frequently used as reference antennas.

Fig 1.5: Horn Antenna

- The **parabolic antenna** consists of an active element at the focus of a parabolic reflector to reflect the waves into a plane wave. Like the horn it is used for high gain, microwave applications, such as satellite dishes.

Fig 1.6: Parabolic Antenna

- The **Yagi-Uda** antenna is a directional variation of the dipole with parasitic elements added which are functionality similar to adding a reflector and lenses (directors) to focus a filament light bulb.

Fig 1.7: Yagi-Uda Antenna

1.2. ANTENNA PARAMETERS

1.2.1. Radiation Pattern:

An antenna radiation pattern or antenna pattern is defined as "a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far field region and is represented as a function of the directional coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization". The radiation property of most concern is the two- or three dimensional spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius.

1.2.2. Radiation Intensity:

Radiation intensity in a given direction is defined as "the power radiated from an antenna per unit solid angle". The radiation intensity is a far-field parameter, and it can be obtained by simply multiplying the radiation density by the square of the distance. In mathematical form it is expressed as

$$\mathbf{U = r^2 W_{rad}}$$

where,

U = radiation intensity (W/unit solid angle)

W_{rad} = radiation density (W/m2)

1.2.3. Gain:

Gain is a parameter that measures the directionality of a given antenna. An antenna with low gain emits radiation about same power in all directions, whereas a high gain antenna preferentially radiates in particular directions. Especially the gain, directive gain or power gain of an antenna is defined as the ratio of intensity of the signal radiated by the antenna in a given direction at an arbitrary distance divided by the intensity radiated at the same distance by a hypothetical isotropic lossless antenna.

Since the radiation intensity from a lossless isotropic antenna equals the power into the antenna divided by a solid angle of 4π Steradians,

$$\boldsymbol{Gain = \frac{4\pi\ radiation\ intensity}{total\ input\ (transmitted) power}}$$

Although the gain of an antenna is directly related to its directivity, antenna gain is a measure that takes into account: the efficiency of the antenna as well as its directional capabilities.

1.2.4. Directivity:

The directivity of the antenna has been defined as “the radiation intensity in a given direction from the antenna divided by the radiation intensity averaged over all directions”. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π. In other words, the directivity of a non-isotropic source is equal to the ratio of its radiation intensity in given direction, over that an isotropic source.

$$\boldsymbol{D = \frac{4\pi U}{P_{rad}}}$$

Where, U is the radiation intensity in (W/unit solid angle) and P_{rad} is total radiated power in (W), D is the directivity of antenna. If the direction is not specified, it implies the direction of maximum radiation intensity (maximum directivity) expressed as

$$\boldsymbol{D = \frac{4\pi U_{max}}{P_{rad}}}$$

1.2.5. Return Loss (S_{11}):

The return loss (RL) is a parameter that indicates the amount of power that is lost to the load and does not return as a reflection. Waves are reflected leading to the formation of standing waves, when the transmitter and antenna impedance do not match. Hence the RL is a parameter to indicate how well the matching between the transmitter and antenna has taken place. The RL is given by

$$\mathbf{s_{11}(dB) = 10log_{10}\frac{p_t}{p_r}}$$

For perfect matching between the transmitter and the antenna, the reflection coefficient Γ=0 and hence RL= ∞ which means no power would be reflected back, whereas Γ= 1 has a RL= 0 dB, which implies that all incident power is reflected back. For practical applications, a VSWR of 2 is acceptable, since this corresponds to reflection coefficient Γ= (1/3) and hence a return loss of 9.54dB or approximately 10dB is acceptable. This is the reason that during bandwidth calculations, 10dB return loss is considered. This 10dB figure carries dependency on frequency band such as the resonant frequency dip should be less than 10dB. Also we decide the bandwidth of an antenna at the two cutting point along 10dB. Also we decide the bandwidth of an antenna at the two cutting point along 10dB.

1.2.6. Voltage Standing Wave Ratio:

As electromagnetic waves travel through the different parts of the antenna system, from the source to the feed line to the antenna and finally to free space, they may encounter differences in impedance at each interface. Depending on the impedance match, some fraction of the wave's energy will reflect back to the source, forming a standing wave pattern in the feed line. The ratio of the maximum power to the minimum power in the wave can be measured and it is called the voltage standing wave ratio (VSWR). A VSWR of 1:1 is ideal. A VSWR of 1.5:1 is considered to be marginally acceptable in low power applications.

Minimizing impedance differences at each interface will reduce VSWR and maximize power transfer through each part of the system.

The VSWR can be expressed as

$$\mathbf{VSWR} = \frac{V_{max}}{V_{min}} = \frac{\mathbf{1}+|\Gamma|}{\mathbf{1}-|\Gamma|}$$

1.2.7. Bandwidth:

The bandwidth is the antenna operating frequency band within which the antenna performs as desired. The bandwidth of a broadband antenna can be defined as the ratio of the higher to lower frequencies of acceptable operation. In other words, the frequency over which the antenna will perform satisfactorily i.e. it's one or more characteristics have acceptable values between the bandwidth limits. The absolute bandwidth (ABW) is defined as the difference of the two edges and the fractional bandwidth (FBW) is designated as the percentage of the frequency difference over the center frequency, as given in equation.

$$\mathbf{ABW = f_H - f_L}$$

$$\mathbf{FBW = 2(f_H - f_L)/(f_H + f_L)}$$

1.2.8. Antenna Efficiency:

Associated with an antenna are a number of efficiencies and can be defined. The total antenna efficiency e_0 is used to take into account losses at the input terminals and within the structure of the antenna. Such losses may be due to

- Reflections because of the mismatch between the transmission line and the antenna
- I^2 R losses (conduction and dielectric)

In general, the overall efficiency can be written as

$$e_0 = e_r e_c e_d$$

where,

e_0 = total efficiency (dimensionless)

e_r = reflection (mismatch) efficiency (dimensionless)

e_c = conduction efficiency (dimensionless)

e_d = dielectric efficiency (dimensionless)

1.2.9. Beamwidth:

Associated with the pattern of an antenna is a parameter designated as beamwidth. The beamwidth of a pattern is defined as the angular separation between two identical points on opposite side of the pattern maximum. In an antenna pattern, there are a number of beamwidths. One of the most widely used beamwidth is the Half-Power Beamwidth (HPBW), which is defined by IEEE as: "In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half value of the beam".

1.2.10. Front-to- Back Ratio:

In telecommunication, the term **front-to-back ratio** can meant he ratio of power gain between the front and rear of a directional antenna. Ratio of signal strength transmitted in a forward direction to that transmitted in a backward direction. For receiving antennas, the ratio of received-signal strength when the antenna is rotated 180°.The ratio compares the antenna gain in a specified direction, i.e., azimuth, usually that of maximum gain, to the gain in a direction 180° from the specified azimuth. A front-to-back ratio is usually expressed in dB.

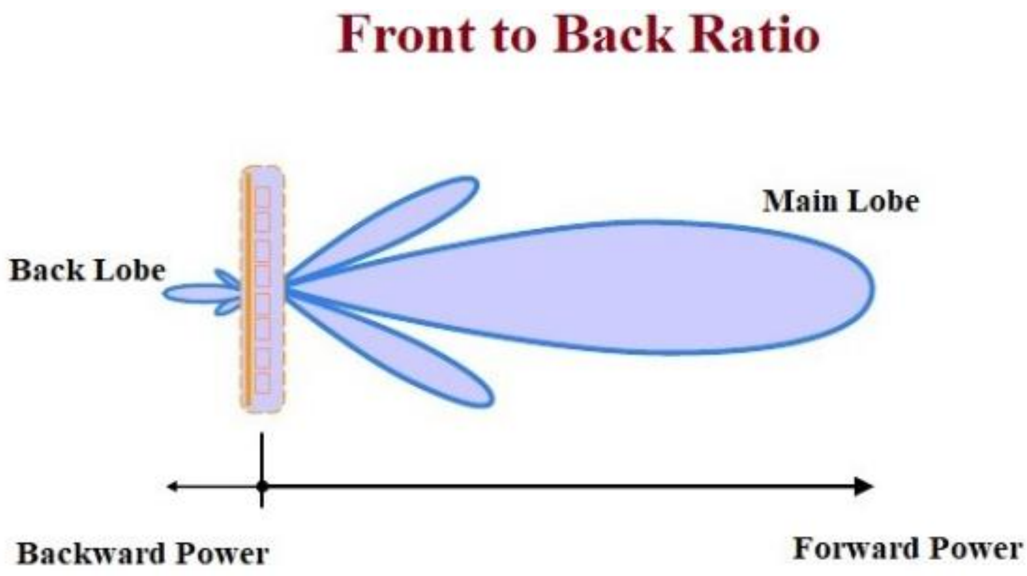

Fig 1.8: Front to Back Ratio

1.2.11. Polarization:

Polarization of the field radiated by the antenna is another important specification. Polarization refers to the path traced by the tip of the electric field vector as a function of time. There are three forms of polarization: linear, circular and elliptic. Linear polarization occurs either when there is only one component of the electric field or when there are two components of the electric field and the phase difference between them is 0° or 180°. The pattern traced by the tip of the electric field vector as time progresses is a line. Circular polarization occurs when there are two components of the electric field, and they are equal in magnitude and one of the components leads the other by 90°. Circular polarization can be either right handed or left handed, depending on the direction in which the rotation of the field occurs with time. Elliptical polarization occurs when the components of the electric field do not have the same magnitude and have an arbitrary phase difference between them; the electric field vector traces out an ellipse with time.

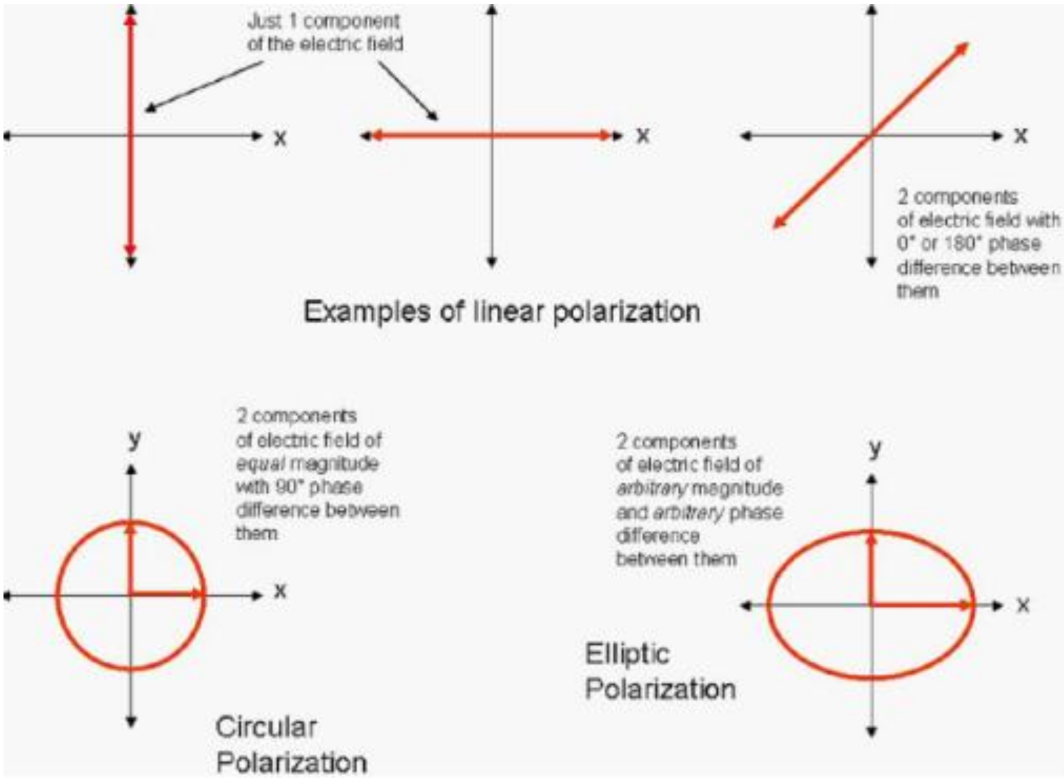

Fig 1.9: Types of Polarizations in Antenna

CHAPTER 2

MICROSTRIP PATCH ANTENNA

2.1. BASIC STRUCTURE OF MICROSTRIP PATCH ANTENNA

Micro strip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation. Micro strip patch antennas are lightweight, small in size and low cost. Also known as "**Printed Antenna**". Ease of mass production using the printed circuits makes them a cheaper option to use. Major advantage is that they can work in multiband of frequencies. These Antennas are mainly used at microwave frequency (above 1 GHz).

The basic design of the antenna consists of Patch (Radiating Element), Substrate and Ground Plane. The typical range for dielectric constant of the substrate being used is $2.2 \leq \varepsilon_r \leq 12$. These antennas are simple to design, easy to modify according to needs, inexpensive and lightweight.

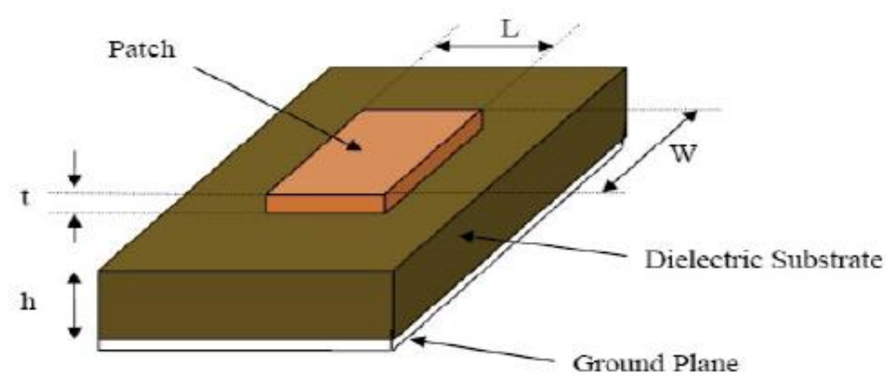

Fig 2.1: Basic Structure of Microstrip Patch Antenna

2.2. BASIC PRINCIPLES OF MICROSTRIP ANTENNA

- The patch acts approximately as a resonant cavity.
- If the antenna is excited at a resonant frequency, a strong field is set up inside the cavity, and a strong current on the (bottom) surface of the patch. This produces significant radiation

2.2.1. Rectangular Patch:

The rectangular patch is by far the most widely used configuration. It is very easy to analyse using both the transmission-line and cavity models, which are most accurate for thin substrates. We begin with the transmission-line model because it is easier to illustrate.

2.2.2. Fringing Fields:

It is the fringing fields that are responsible for the radiation. Note that the fringing fields near the surface of the patch antenna are both in the +y direction. Hence, the fringing E-fields on the edge of the micro strip antenna add up in phase and produce the radiation of the micro strip antenna. This paragraph is critical to understanding the patch antenna. The current adds up in phase on the patch antenna as well; however, an equal current but with opposite direction is on the ground plane, which cancels the radiation. The micro strip antenna's radiation arises from the fringing fields, which are due to the advantageous voltage distribution; hence the radiation arises due to the voltage and not the current. The patch antenna is therefore a "voltage radiator", as opposed to the wire antennas, which radiate because the currents add up in phase and are therefore "current radiators".

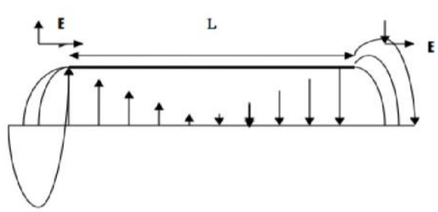

Fig 2.2: Radiation due to fringing effect

2.3. TYPES OF MICROSTRIP ANTENNAS

There are different types of micro strip antennas which are classified based on their physical parameters. These different types of antennas have many different shapes and dimensions. The basic categories of these micro strip antennas can be classified into four, which are:

1) Microstrip patch antenna
2) Microstrip dipoles
3) Printed slot antennas
4) Microstrip travelling wave antennas

2.3.1. **Microstrip patch antennas** are used because of:

1) Flat surface makes them ideal for mounting on airplane
2) Impedance matching fairly simple
3) Microstrip patch antennas have a very high antenna quality factor (Q).
4) These antennas are simple to design, easy to modify according to needs, inexpensive, lightweight.

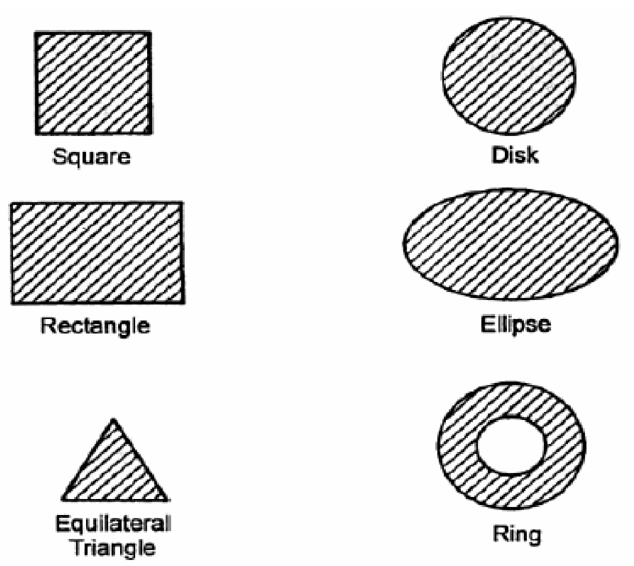

Fig 2.3: Microstrip patch antenna shapes commonly used in practice

Substrates with lower dielectric constant are preferred for antenna design for better performance. The possible shapes for conducting patch are shown in figure 2.3, but rectangular and circular configurations are most commonly used configurations. The main parameters of a Microstrip antenna are its length, width, input impedance, gain and radiation pattern. The length of the antenna should be less than half wavelength in the dielectric.

2.3.2. Microstrip or Printed Dipole Antennas:

Microstrip or printed dipole differs geometrically from rectangular patch antennas in their length to width ratio. The width of a dipole is typically less than 0.05λo. The radiation patterns of the dipole and patch are similar owing to similar longitudinal current distributions. However, the radiation resistance, bandwidth, and cross polar radiation differ widely. These are well suited for higher frequencies for which the substrate can be electrically thick and therefore can attain significant bandwidth. The choice of feed mechanism is very important in the microstrip dipoles and should be included in the analysis.

2.3.3. Printed Slot Antennas:

Printed slot antennas comprise a slot in the ground plane of a grounded substrate. The slot can have virtually any shape. Theoretically, most of the microstrip patch shapes can be realized in the form of a printed slot. Like microstrip patch antennas, the slot antennas can be fed either by a microstrip line or a coplanar waveguide.

2.3.4. Microstrip Travelling-Wave Antennas:

A microstrip travelling wave antenna may consist of chain-shaped periodic conductors or a long microstrip line sufficient width to support a TE mode. The other end of the traveling wave antenna is terminated in a matched resistive load to avoid the standing wave on the antenna. Travelling wave microstrip antennas can be designed so that the main beam lies in any direction from broadside to endfire.

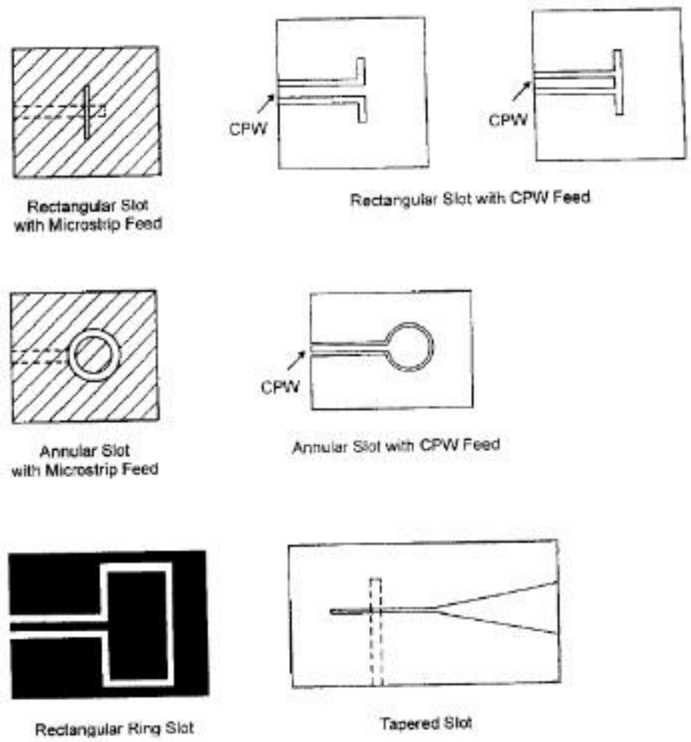

Fig 2.4: Printed Slot Antennas

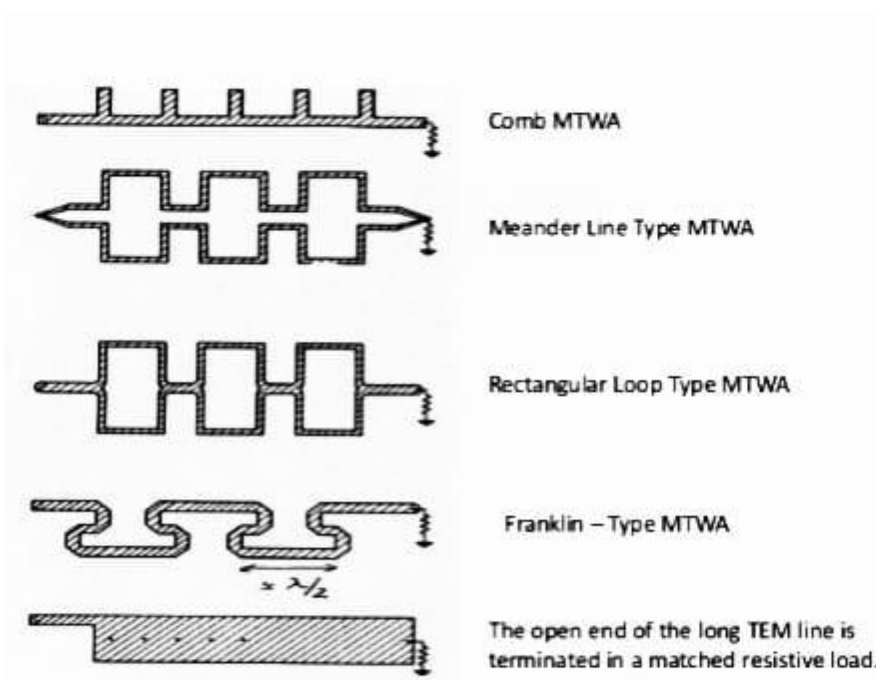

Fig 2.5: Microstrip Travelling Wave Antennas

2.4. FEEDING TECHNIQUES OF MICROSTRIP PATCH ANTENNA

2.4.1. Microstrip Line Feed:

In this type of feed technique, a conducting strip is connected directly to the edge of the Microstrip patch as shown in Figure 2.4. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure. The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna. The feed radiation also leads to undesired cross polarized radiation.

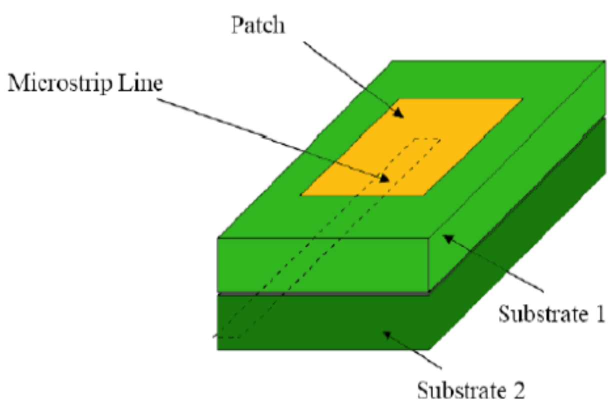

Fig 2.6: Microstrip Line Feed

2.4.2. Coaxial Feed:

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure 2.5, 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. The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, a major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda_o$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems.

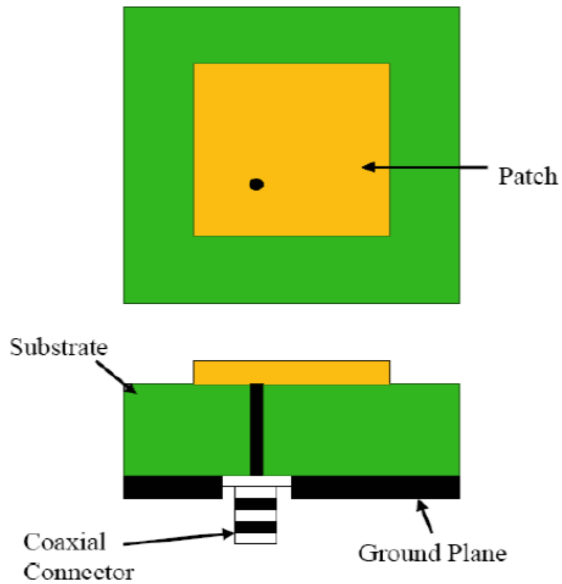

Fig 2.7: Coaxial Feed

2.4.3. Aperture Coupled Feed:

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 2.6. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane. The coupling aperture is usually centered under the patch, leading to lower cross-polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth.

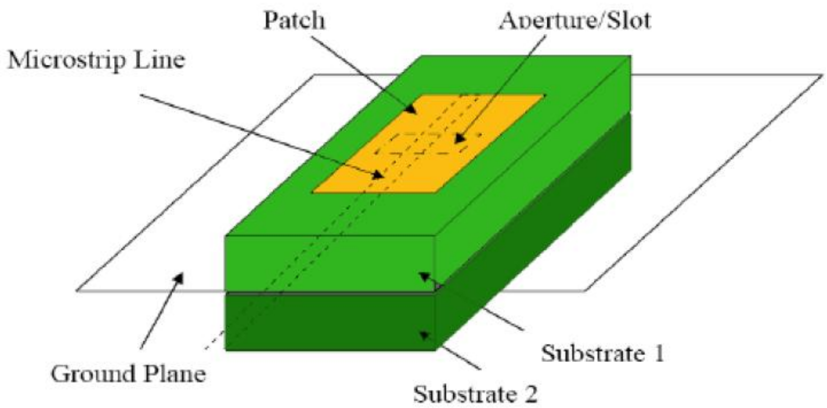

Fig 2.8: Aperture Coupled Feed

2.4.4 Proximity Coupled Feed:

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 2.7, 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. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%), due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances. Matching can be achieved by controlling the length of the feed line and the width to line ratio of the patch. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the antenna.

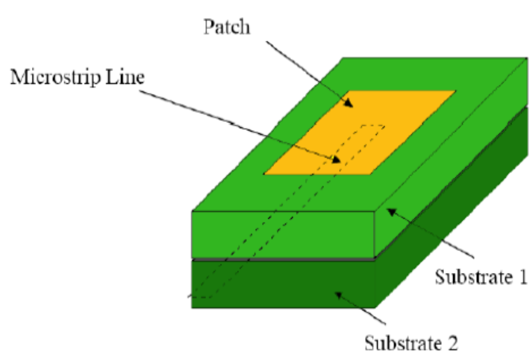

Fig 2.9: Proximity Coupled Feed

2.5. COMPARISON OF DIFFERENT FEEDING TECHNIQUES

Characteristics	Microstrip Line Feed	Coaxial Feed	Aperture Coupled Feed	Proximity Coupled Feed
Spurious feed radiation	More	More	Less	Minimum
Reliability	Better	Poor due to soldering	Good	Good
Ease of Fabrication	Easy	Soldering and drilling needed	Alignment required	Alignment required
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth (Achieved with impedance matching)	2-5%	2-5%	2-5%	2-5%

Table 2.1 Comparison of different feeding techniques

2.6. ADVANTAGES OF MICROSTRIP PATCH ANTENNA

Microstrip patch antennas found attention of scientific community due to its inherent well known advantages over other conventional antenna structures.

Some of their principal advantages are given below:

- Light weight and low volume.
- Low fabrication cost and readily amenable on mass production.
- The antennas may be easily mounted on missiles and satellites without major alteration.
- Linear and circular polarizations are possible with simple changes in feed position.
- The antennas have low scattering cross section.
- No cavity backing is required.

- Capable of dual and triple frequency operations.
- Feed lines and matching networks may be fabricated simultaneously with antenna structure

2.7. DISADVANTAGES OF MICROSTRIP PATCH ANTENNA

As compared to conventional antennas, Microstrip patch antennas suffer from many drawbacks, some of them are

- Due to losses in the dielectric substrate result in low efficiency.
- Low gain.
- Low power handling capacity.
- Poor radiation pattern due to surface waves which travel within the substrate and scatter at surface discontinuities.
- Require quality substrate and good temperature tolerance

2.8. APPLICATIONS OF MICROSTRIP PATCH ANTENNA

Some typical system applications which employ Microstrip technology are given below:

- Satellite communications
- Aircraft antennas
- Missiles and telemetry
- Missiles Guidance Systems
- Biomedical Instruments
- Radar systems
- Satellite navigation receiver
- Global positioning system

2.9. S-BAND APPLICATIONS

Frequency Band Designation	Frequency Range	Wavelength
S Band	2 to 4 GHz	15 to 7.5 cm

Table 2.2. S-Band Frequency Range and Wavelength

Applications of S-Band:

- Communication satellites
- Weather Radar
- Surface Ship Radar
- Wireless LAN
- Multimedia applications in mobile, TV and satellite radio
- Consumer electronic appliances like microwave oven, Bluetooth headphones etc.

CHAPTER 3

DESIGN OF HEXAGONAL MICROSTRIP ANTENNA

3.1 REASONS FOR SELECTING HEXAGONAL PATCH

3.1.1. Comparison with Rectangular and Square Patches:

When compared with the rectangular and square antennas, the hexagonal antenna shows increased bandwidth, gain, return loss and directivity. So by applying a better substrate between ground and the patch much higher values are obtained for hexagonal antenna.

Parameters of Comparison	Rectangle	Square	Hexagonal
Frequency	3.5GHz	3.5GHz	3.5GHz
Dielectric substrate	Rogers RT /duroid 5880 tm	Rogers RT /duroid 5880 tm	Rogers RT /duroid 5880 tm
Relative Permittivity (ε_r)	2.2	2.2	2.2
Impedance Matching	50Ω	50Ω	50Ω
Feeding Technique	Microstrip Line Feed	Microstrip Line Feed	Microstrip Line Feed
Return Loss	-7.8dB	-11.2dB	-18dB
Peak Gain	2.7736	2.60674	2.9877
Peak Directivity	2.8101	2.62241	3.0631
Radiation Efficiency	0.97042	0.97482	0.9917

Table 3.1: Comparison with Rectangular, Square and Hexagonal Antennas

3.1.2. Comparison with Circular Patch:

Circular shaped antennas does not allow parasitic coupling due to curved edges whereas the Hexagonal antenna does. So Hexagonal antenna gives better bandwidth.

3.1.3. Two Feeding Positions:

For Hexagonal shape, two feeding positions are possible, one at vertex and other at the edge of the shape.

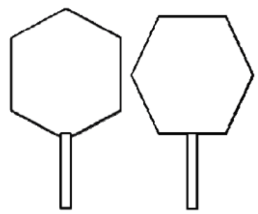

Fig 3.1: Feeding Positions for Hexagon

3.2. SPECIFICATIONS OF THE DESIGN

Hexagonal Microstrip antenna is designed using Ansoft HFSSV18 simulation tool. The antenna to be designed over the operating frequency of 3GHz using the substrate material as FR4 which has the dielectric constant of 4.6(ε_r) and substrate thickness of 1.6mm. The antenna can be used for S-band applications like communication satellites, weather radar, surface ship radar, wireless LAN etc.

3.2.1. Microstrip Line Feed:

Microstrip Line feed used in the patch antennas. This is the most basic and easy method used in the feed for Microstrip patch antennas. This feeding technique is used for the design of the hexagonal microstrip antenna. In this feeding technique, a conducting strip of the same conductor is directly attached to the edge of the patch. This method of feeding provides ease of fabrication, simplicity in modelling and also impedance matching.

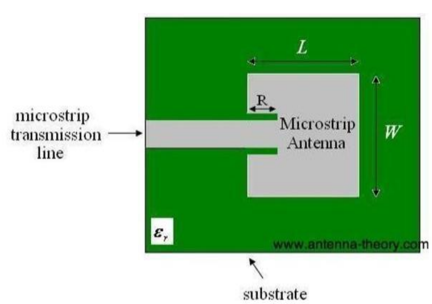

Fig.3.2. Microstrip line feed patch antenna

3.2.2. Fr-4 Substrate:

FR-4 glass epoxy is a popular and versatile high-pressure thermoset plastic laminate grade with good strength to weight ratios. With near zero water absorption, FR-4 is most commonly used as an electrical insulator possessing considerable mechanical strength. The material is known to retain its high mechanical values and electrical insulating qualities in both dry and humid conditions. These attributes, along with good fabrication characteristics, lend utility to this grade for a wide variety of electrical and mechanical applications. In this design, FR-4 substrate of thickness 1.6mm with dielectric constant 4.6 is used.

3.2.3. Ground Plane and Excitation Port:

The ground plane has been modelled as a finite plane. In this antenna, the ground plane doesn't cover the bottom portion of the hexagonal patch. It only covers the bottom of the microstrip line feed. This particular configuration helps the antenna to form a near omnidirectional radiation pattern. The excitation port is given in the rectangular pattern. The excitation port is given in the rectangular port connecting the ground plane and the microstrip line feed. A very thin layer of copper conductor is given to the radiating element and the microstrip line feed of thickness 0.035mm.

3.2.4. Frequency of Operation:

The resonant frequency of the antenna depending on the S-Band application. The presented antenna is designed for S-Band that is from 2GHz to 4GHz approximately. The resonant frequency selected for the design is 3GHz. The antenna can be used for S-band applications like communication satellites, weather radar, surface ship radar, wireless LAN etc.

3.3. DESIGN EQUATIONS

Initially a hexagonal antenna has been designed by reversing the calculations of effective antenna radius and effective length to determine the dimensions of the hexagonal antenna for the given resonant frequency 3GHz.

- **Resonant Frequency:**

$$f_c = \frac{c \times k_{mn}}{2\pi a_{eff}\sqrt{\varepsilon_{eff}}} = 3 \text{ GHz}$$

where,

c - velocity of light (3×10^8 m/s)

k_{nm} - wave number (1.84118)

ε_{eff} - effective dielectric constant (4.02)

a_{eff} - effective radius of antenna (14.61mm)

- **Height of the substrate:**

$$h \leq \frac{0.3\times c}{2\times\pi\times f_c\times\sqrt{\varepsilon r}} = 2.2\text{mm}$$

where,

c - velocity of light (3×10^8 m/s)

f_c - resonant frequency (3 GHz)

ε_r - dielectric constant (4.6)

- **Effective dielectric Constant:**

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{w}\right]^{\frac{-1}{2}} = 4.02$$

where,

h - height of the substrate(1.6mm)

W - width of the patch(16.5mm)

ε_r - dielectric constant (4.6)

- **Length and Width of the patch:**

$$L = \sqrt{3}S = 19.05mm$$

$$W = 3S/2 = 16.5mm$$

where,

S - side of the hexagon patch (11mm)

- **Increase in Length:**

$$\Delta L = 0.412h \frac{(\in_{eff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\in_{eff} - 0.258)\left(\frac{w}{h} + 0.8\right)} = 0.4486mm$$

where,

h - height of the substrate(1.6mm)

W- width of the patch(16.5mm)

ε_{eff} - effective dielectric constant (4.02)

- **Effective Length and Effective Width of the equivalent Rectangular microstrip antenna:**

$$L_{eff} = L + 2\Delta L = 19.94mm$$

$W_{eff} = W + 2\Delta W = 33.62mm$

where,

L,W - length and width of the patch

Δ L, ΔW - increase in length and width

- **Effective Antenna Radius:**

$$a_{eff} = \sqrt{\frac{L_{eff} \times W_{eff}}{\pi}} = 14.61mm$$

where,

L_{eff} - effective length

W_{eff} - effective width

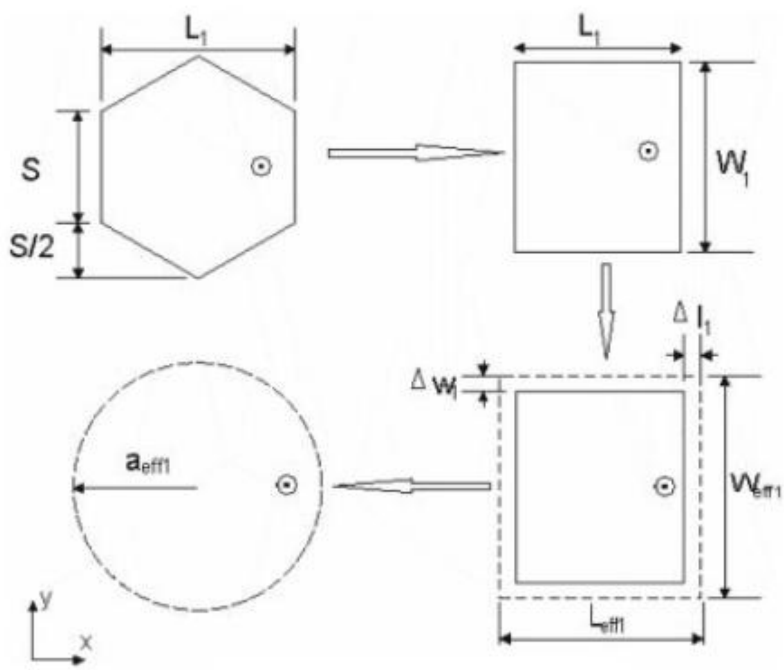

Fig 3.3: Equating the structure of the Hexagon with Rectangle and Circular shapes

3.4. HIGH FREQUENCY STRUCTURE SIMULATOR

HFSS is a commercial finite element method solver for electromagnetic structures from Ansys Corporation. The acronym originally stood for **High Frequency Structure Simulator (HFSS).** It is one of several commercial tools used for antenna design, and the design of complex RF electronic circuit element including filters, transmission lines, and packaging. It was originally developed by professor Zoltan cendes and his students at Carnegie Mellon University. Prof. Cendes and his brother Nicholas cendes founded and sold HFSS standalone under a 1989 marketing relationship with Hewlett - Packard, and bundled into Ansoft products.

HFSS benefits from multiple state-of-the-art solver technologies, allowing users to match the appropriate solver to any simulation need. Each solver is a powerful, automated solution process in which the user specifies geometry, material properties and the desired range of solution frequencies. Based on this input, HFSS automatically generate the most appropriate, efficient and accurate mesh for the simulation, thereby leading to the highest-field solution possible.

HFSS results yields information critical to your engineering designs. Typical results include scattering parameters (S, Y, Z), visualization of 3-D electromagnetic fields (transient or study State), transmission path losses, reflection losses due to impedance mismatches, parasitic coupling, and near- and far- field antenna patterns.

HFSS software uses mainly finite element method that is the structure will be sub divided into smaller elements. The fields assigned to the structures must satisfy the maxwell's equations across the inter element junctions which are defined in the electromagnetic theory. Using HFSS in the design flow reducing engineering costs, mitigates risk, and reduces time to market. HFSS version 18 is used to design the featured antenna in the project.

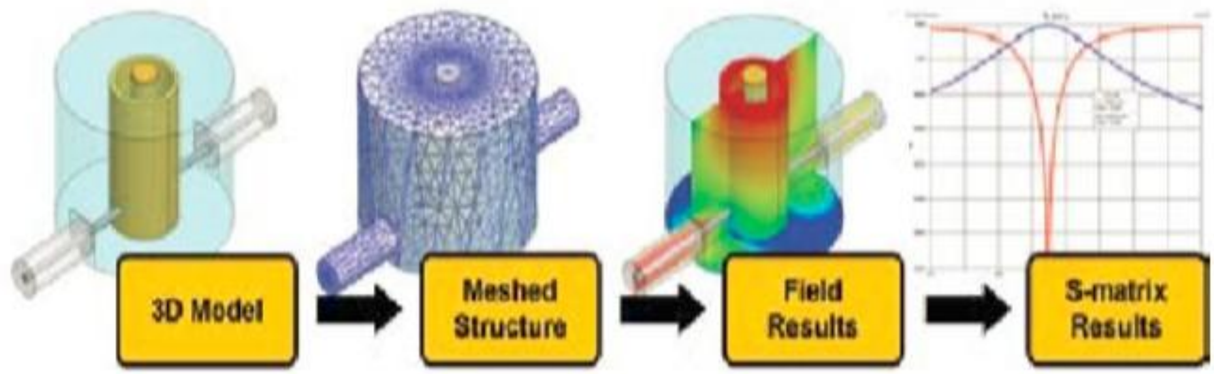

Fig 3.4.: Process of Finite Element Method

The main steps involved in HFSS simulation are

(i) Design the geometry

(ii) Assignment of boundaries to patches, feeds etc.

(iii) Assignment of excitations to ports

(iv) Setting up the solution

(v) Solving

(vi) Post - processing the results

The initial step is to design the HFSS model in driven terminal which consists of the physical dimensions based on the user constraints. After the designing part the boundaries has to be assigned to the united structures that is the patch and the feed will be united by using the command unite in HFSS software. The excitation to the ports has to be assigned which is used to improve the results. After assigning boundaries and excitations solution setup, mesh operations has to be created. Once if all the assignment has been done perfectly then we need to validate check. If there are any errors we need to rectify those errors or else the required results are to be observed for the designed patch antenna. In the driven terminal solution type the scattering matrix is expressed in terms of terminal voltages and currents. If we assign radiation then it creates an open model. By default the perfect electric conductor creates a closed model. The absorption of wave is done at radiation boundary.

3.5. DESIGN STEPS OF HEXAGONAL MICROSTRIP ANTENNA IN HFSS

How to start HFSS?

HFSS should be installed on the computer or station working on. There should be an **HFSS** icon on the desktop you can double click on it to launch HFSS, or can go to "**Start**‖ button on the lower left corner of the screen, click on it, then go to "**Programs**‖ button and a list of programs will pop up. Go to "**Ansoft<< HFSS 18<< HFSS V18**‖.

How to Open a New Project?

When started **HFSSV18**, a project is listed in the project tree in the **Project Manager** window and is named **project1** by default. Project definitions, such as material assignment, boundary conditions, and excitation ports are stored under the project name.

Save the Project

On the **File** menu, click **Save As.** Use the file browser to locate the folder to save the project, such as C:\Ansoft\HFSS18\Projects, and then double-click the folder's name. Type **Hexagon** in the **File Name** text box and click **Save**. Now, the project is saved in the folder that is selected by the file name with an extension of hfss: **Hexagon.hfss**

Insert an HFSS Design

On the **Project** menu, click **Insert HFSS Design**. The new design is listed in the project tree. It is named Model by default. The **3D Modeler** window appears to the right of the **Project Manager**. If there is a need to rename the model by right-clicking on the Model and then click **Rename**. Type the name then press **Enter**.

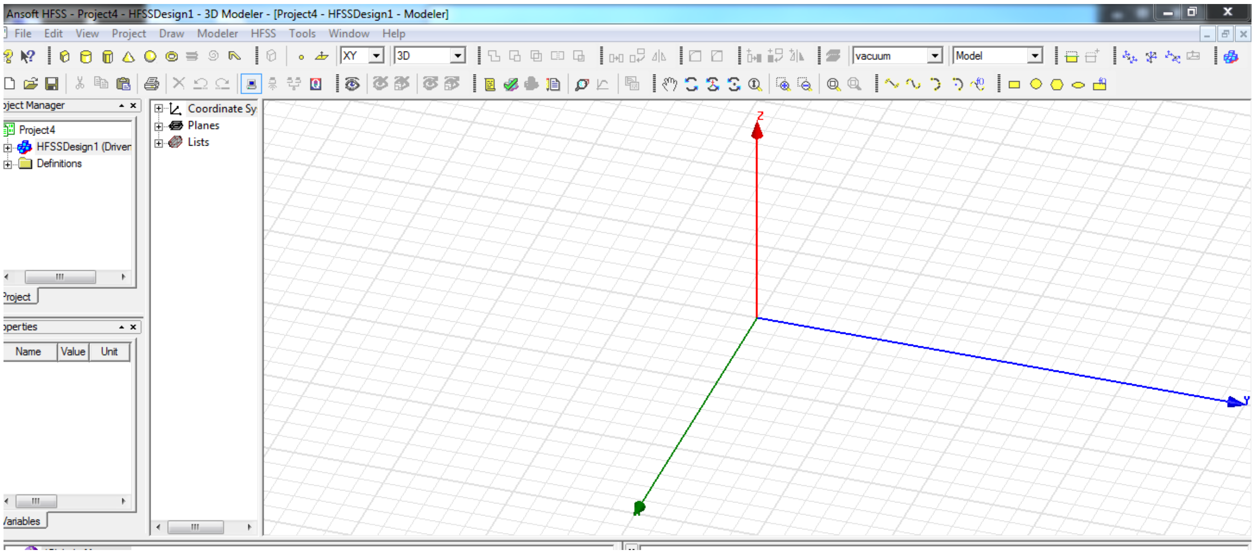

Fig 3.5: HFSS Window

Select a Solution type

Now specify the design's solution type. Set up the design for analysis, available settings will depend upon the solution type. For this design, choose **Driven Modal** as the solution type, which is appropriate when calculating mode-based S-parameters of antenna problems driven by a source. On the **HFSS** menu, click **Solution Type**. In the **Solution type** dialog box, select **Driven Modal**, and then click **OK**. In the driven terminal solution type the scattering matrix is expressed in terms of terminal voltages and currents. If we assign radiation then it creates an open model. By default the perfect electric conductor creates a closed model. The absorption of wave is done at radiation boundary.

Set the Drawing Units

Now set the units of measurement for drawing the geometric model. On the **3D Modeler** menu, click **Units.** In the **Set Model Units** dialog box, click **mm** in the **Select Units** pull-down list, and then click **OK.**

Creating the Model

The Hexagonal patch antenna is created by three bricks: the first for the radiating plate, the second for the Microstrip line feed, and the third for the substrate (FR4). The ground plane is specified by a finite conducting boundary condition. The coordinates are assigned as follows. The center position for the hexagonal patch is at (0,0,0). The Length, *L*, of the substrate and the width, *W*, are chosen as 60mm and 60mm, respectively and a thickness of 1.6mm, which is the commercial height for FR-4 substrate. As for the hexagonal patch, the length is 11mm and all the sides are equal as it is a regular hexagonal polygon.

The patch's starting point is located at (0,11,0). The total width of the ground plane stretches 28.476mm in the positive x-direction and total length stretches of 60mm in the positive y-direction. Moreover, the feed line should be located somewhere between the values of the starting point and ending point of the patch. Although the feed line is located at the midpoint, we have to shift the feed line a little to the upper or lower side to achieve impedance matching.

The feed line is taken of width 2mm and length equal to that of the ground that is 28.467mm. Microstrip line Feed and patch is combined using unite operation in HFSS software. The source rectangle is given in the y-z plane (x=0) where its y starting point is the same as the feed's starting point cover 2mm in that direction and the z point covers 1.6mm that is the height of the substrate. The air box dimensions are taken as half of the wavelength distance at resonant frequency from all the six sides of the antenna. The antenna is kept exactly in the middle of the air box. Understanding the dimensions of the design of the hexagonal microstrip antenna is very important. Now follow the following tables of coordinates.

- A **hexagonal patch** is to be created with vertex position at (0,0,0) with 11mm of the side length and copper conductor should be given to the patch with the thickness of 0.035mm.

Name	Value	Unit	Evaluated Value	Description
Command	CreateRegularPolyhedron			
Coordinate Sys...	Global			
Center Position	0 ,0 ,0	mm	0mm , 0mm , 0mm	
Start Position	0 ,11 ,0	mm	0mm , 11mm , 0...	
Axis	Z			
Height	0.035	mm	0.035mm	
Number of Seg...	6		6	

Fig 3.6: Hexagonal Patch Dimensions

- A **microstrip line feed** of the length 28.476mm and width of 2mm is to be created and copper conductor is to be given with the thickness of 0.035mm.

Coordinates Position (mm)	Size (mm)
x = 9.524	x = 28.476
y = -1	y = 2
z = 0	z = 0.035

Table 3.2: Feed Line Dimensions

- A **substrate** of FR-4 material is to be created with 60mm as length and width and 1.6mm as thickness.

Coordinates Position (mm)	Size (mm)
x = -21.998	x = 60
y = -30	y = 60
z = 0	z = -1.6

Table 3.3: Substrate Dimensions

- An **air box** is to be created with the dimensions given in the below table.

Coordinates Position (mm)	Size (mm)
x = -74.8	x = 160
y = -80	y = 160
z = 50.8175	z = -101.635

Table 3.4: Air box dimensions

- A **ground plane** with finite conductivity is to be created with a length of 28.476mm and width of 60mm below the substrate material.

Coordinates Position (mm)	Size (mm)
x = 38.002	x = -28.476
y = -30	
z = -1.6	y = 60

Table 3.5: Ground Dimensions

- A rectangle for the **source** is to be created in the yz- direction plane of the antenna axis with a length of 2mm and width of 1.6mm.

Coordinates Position (mm)	Size (mm)
x = 38	y = 2
y = -1	
z = 0	z = -1.6

Table 3.6: Source Dimensions

Drawing the Model

Drawing the model would now be easy. First, start by drawing the ground plane. Please refer to the coordinates of the Ground Plane, Table 3.5 Select the menu item **Draw,** in that click on **Rectangle**. Using the coordinate entry fields in Table 3.5, enter the box position (x, y, z) then enter the size of rectangle. The dimensions of the ground plane are given. A properties dialog window appears, makes sure to have your coordinates set right in the **Position, X size, Y size,** and **Z size values**. Click on **Attribute tab** and enter **ground** in the value of the name. Then choose the C**olour** and **Transparency** value of the preference. Click the **OK** button.

Second, draw the substrate. The substrate has the same width of the ground plane but length is of the feed line. Remember that the ground plane lies at $z = 0$ and is of zero thickness (dz=0), so the substrate has to be of 1.6 mm in thickness and since the starting point was at zero, so the full height is in -*z*-direction. **Draw,** in that click on **Box** using the coordinates in Table 3.3, set the position of the box (*x, y, z*) and enter the opposite corner of the box (dx, dy, dz). The properties dialog window pops up, make sure all the coordinates are right. Click the Attribute tab; enter **Substrate** in the name value box. Now assign the material to be **FR4** of relative permittivity 4.6. Click **OK.** Again choose **Colour** and **Transparency** value of preference. Click the **OK** button.

Third, create the hexagon patch. Knowing that the patch should be in the centre, the coordinates are easy to calculate from the ground and substrate dimension. The dimensions are given in the Fig 3.5, set the position of the 3d regular hexagon polygon (*x, y, z*) and enter the size of the hexagon as 11mm. The properties dialog window pops up, make sure all the coordinates are right. Click the Attribute tab; enter **Patch** in the name. Click **OK.** Again choose **Colour** and **Transparency** value of the preference. Click the **OK** button.

Fourth, create the Microstrip line feed. The Microstrip line's position is chosen somewhere between the ends of the patch. In reality it should be at the middle, however, it is shifted more to one side of the patch for impedance matching purposes. **Draw** in that click on **Rectangle** using the coordinates in Table 3.2, set the position of the box (*x, y, z*) and enter the size of the rectangle. The properties dialog window pops up, make sure all the coordinates are right. Click the Attribute tab; enter **Feed Line** in the name value box. Click **OK.** Again choose **Colour** and **Transparency** value of the preference. Click the **OK** button.

It is known that the **Patch** and **Strip Line** should be one object. So, there is a need to unite them. Click on both objects that are needed to unite, i.e. **Patch** and **StripLine** in the history tree. Click on one and hold the **CTRL** key and click on the other. Click **3D Modeler > Boolean > Unite.** The two objects are united now. The steps can be checked in the history tree and in case if there is a need to delete a previous step/command, click **Edit > Undo**.

Fifth, create the source for the antenna structure. The rectangle for the source should be drawn in the yz- direction of the plane. In reality it should be at the middle, however, it is shifted more to one side of the patch for impedance matching purposes. **Draw** in that click on **Rectangle** using the coordinates in Table 3.6, set the position of the box (*x, y, z*) and enter the size of the rectangle. The properties dialog window pops up, make sure all the coordinates are right. Click the Attribute tab; enter **source** in the name value box. Click **OK.** Again choose **Colour** and **Transparency** value of the preference. Click the **OK** button.

Sixth, create the air box for the antenna structure. The box filled with air should be drawn with half wavelength of the resonant frequency of the antenna structure. **Draw** in that click on **box** using the coordinates in Table 3.6, set the position of the box (*x, y, z*) and enter the size of the rectangle. The properties dialog window pops up, make sure all the coordinates are right. Click the Attribute tab; enter **air box** in the name value box. Click **OK.** Again choose **Colour** and **Transparency** value of the preference. Click the **OK** button.

Assign Boundary

Now the model has been created, need to assign boundary conditions. Firstly in HFSS, radiation boundaries are used to simulate open problems that allow waves to radiate infinitely far into space. HFSS absorbs the wave at the radiation boundary, essentially ballooning the boundary infinitely far away from the structure. In this case, our **ABC** (Absorbing Boundary condition) is an air box. **Draw > Box** using the coordinates in Table 3.6. The boundary condition should satisfy a certain distance from the antenna. Normally, its value is chosen $\lambda/4$, where λ is calculated from $\lambda = c/f$, where c is 3×10^8 m/s and f is the resonant frequency in (GHz). In this case, we are extending the size of the radiation box up to $\lambda/2$ distance from all faces of the antenna substrate.

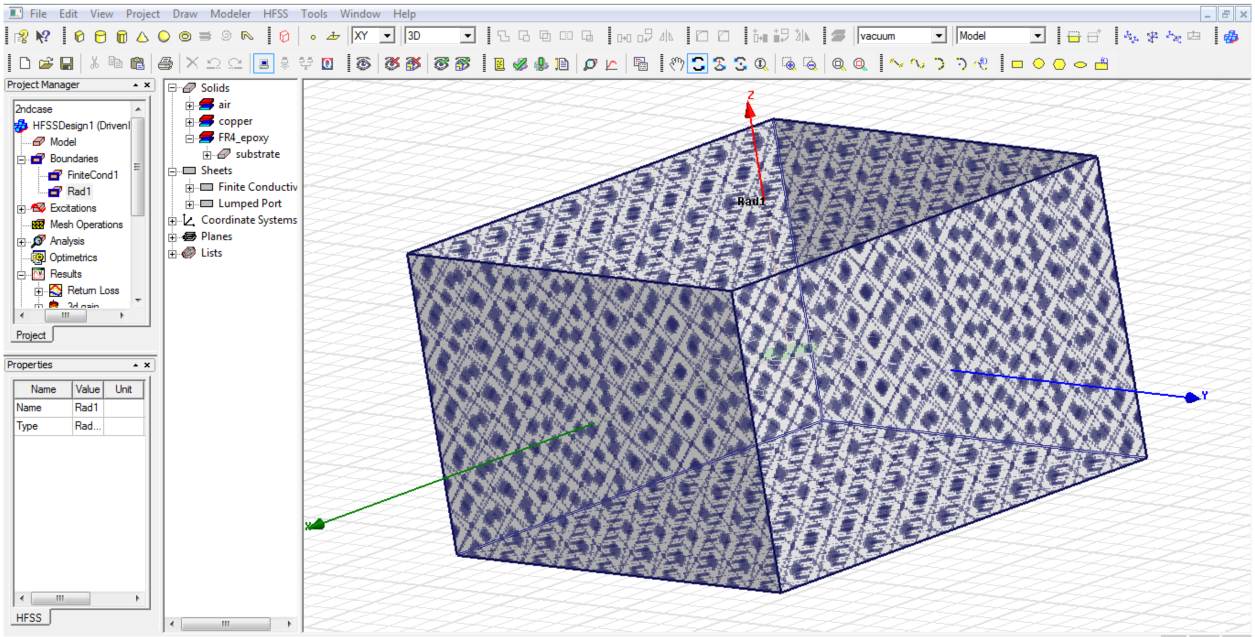

Fig 3.7: Radiation boundary

Secondly, we assign finite conductivity to the ground of the antenna structure as per the design specifications of the project. Select the ground, right click got to **assign boundary**, in that select **finite conductivity** and **click ok**.

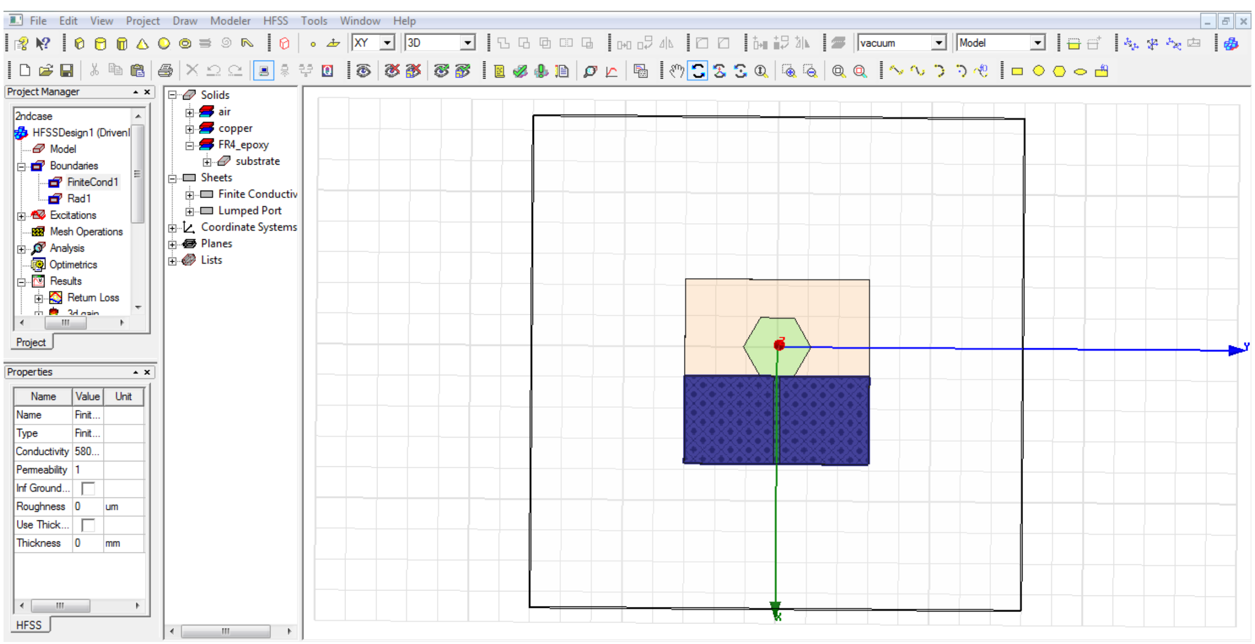

Fig 3.8: Finite Conductivity

Assign Excitation

Having the entire model set now, the only missing part is the excitation to the source. The excitation is a waveguide port at the beginning of the Microstrip line feed. The reference plane of this port is located directly at the beginning of the radiating plane. Antennas are excited through the port. Select the source rectangle from history tree, **right-click** and **assign excitation.** In that we have wave port and lumped port. In this case, we use lumped port as internally the operation should be done. Select **Lumped port** then click next, now define the integration line. Normally, integration line is defined from the bottom middle point to the upper middle point. Keep other values as default. Click **Finish**.

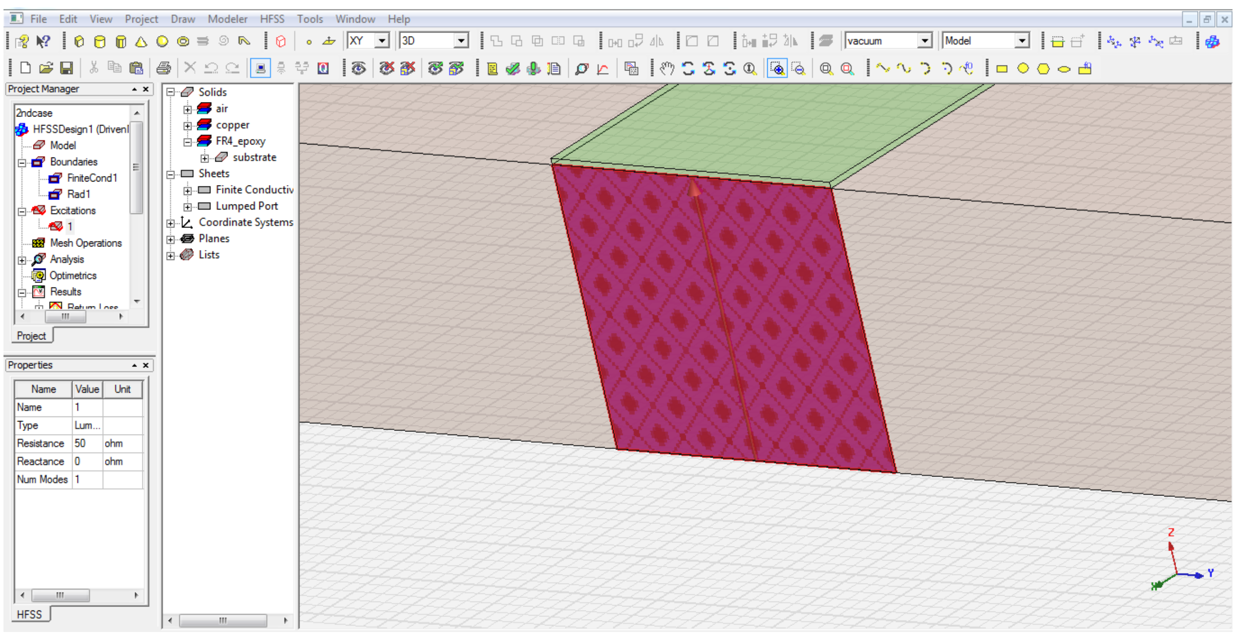

Fig 3.9: Lumped Port

Analysis Setup

Finally, the model is ready to run. Now identify the analysis setup. To create an analysis setup, select the menu item **HFSS > Analysis Setup > Add Solution Setup.** In the Solution Setup window, click the general tab, **Solution frequency** is 3 GHz, **Maximum Number of Passes** is 20 and **Maximum Delta S per Pass** is 0.02. Click **OK** button.

Add Frequency Sweep

To add a frequency sweep, select the menu item **HFSS > Analysis Setup > Add Sweep**. Select Solution Setup: Setup1. Click OK button. Then Edit Sweep Window. **Sweep Type: Fast**, Frequency Setup Type: Linear Count, **start: 1 GHz, Stop: 6 GHz**, Count: 421. Click OK button. Similarly add another **Sweep Type: Discrete** for this design to obtain few plots.

Model Validation

To validate the model, select the menu **HFSS > Validation Check**. Click the **Close** button. To view any errors or warnings messages, use the Message Manager. To Zoom Out to fit, click **CTRL+D**.

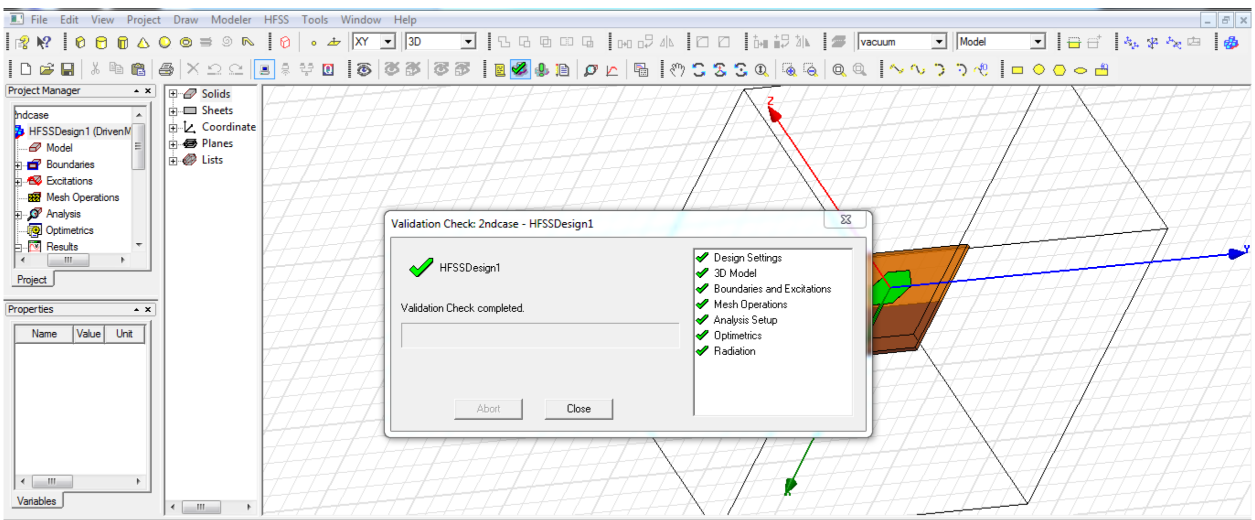

Fig 3.10: Validation Check

Save Project and Analyze

To save the project, in the Ansoft HFSS window, select the menu item **File > Save As.** From the **Save As** window, type the file name. Click **Save** button. To start the solution process, select the menu item **HFSS > Analyze.**

Final Model of the Antenna in HFSS

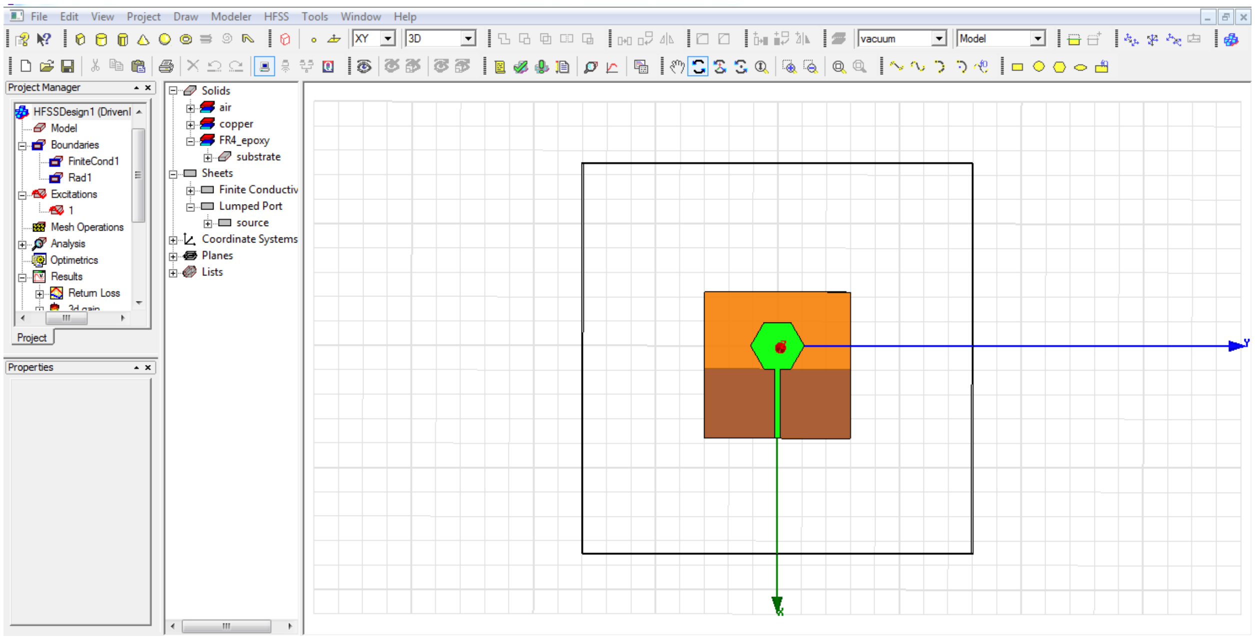

Fig 3.11.: Final Model of the Hexagonal Microstrip Patch Antenna in 2 Dimensional View

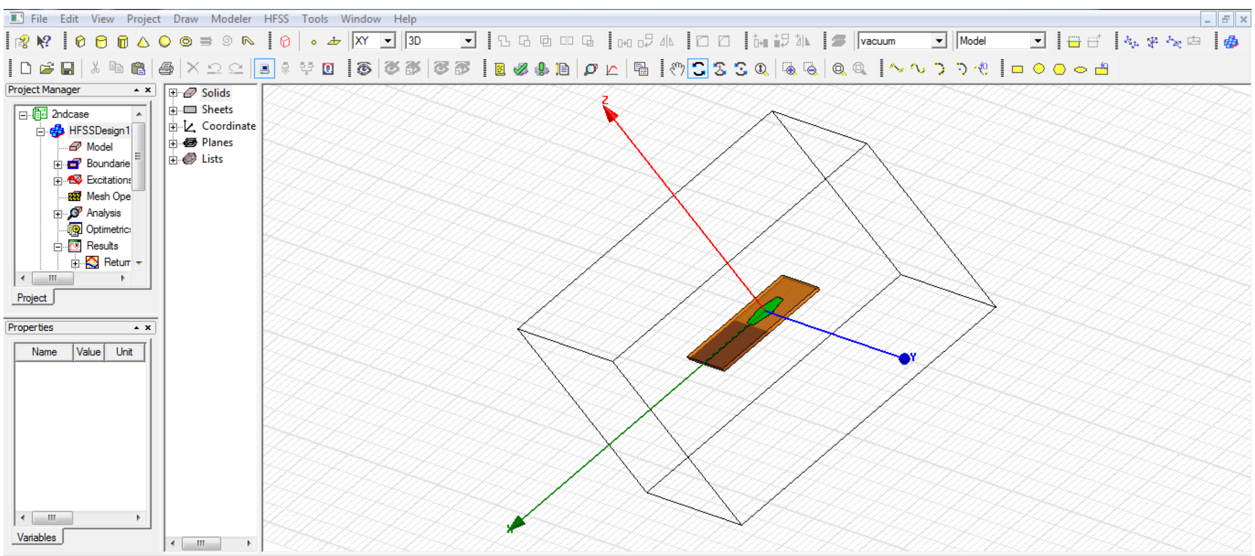

Fig 3.12.: Final Model of the Hexagonal Microstrip Patch Antenna in 3 Dimensional View

CHAPTER 4

SIMULATION RESULTS

4.1. RESULTS

4.1.1. 2D Radiation Pattern

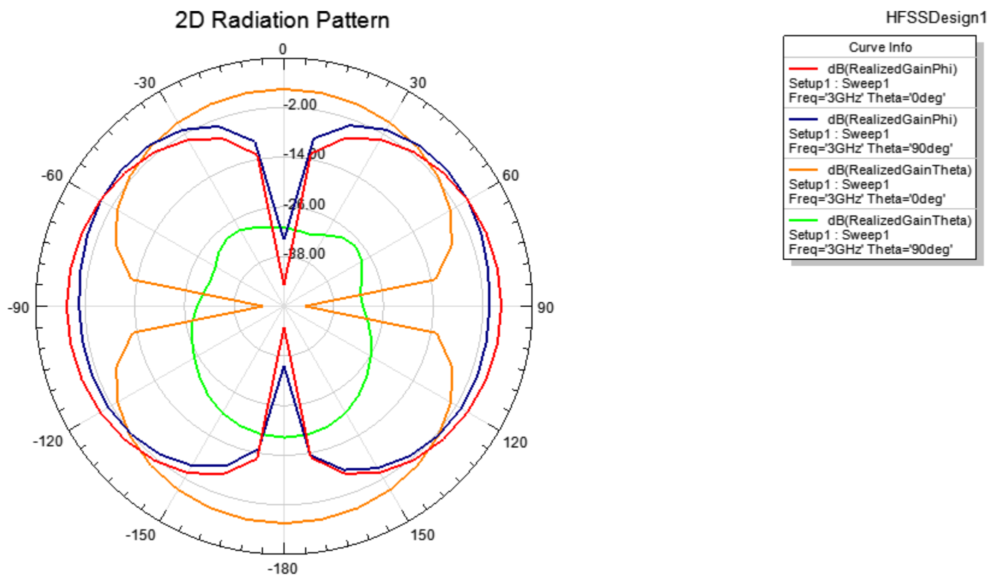

Fig 4.1: 2D Radiation Pattern of the Hexagonal Microstrip Antenna

4.1.2. 3D Radiation Pattern

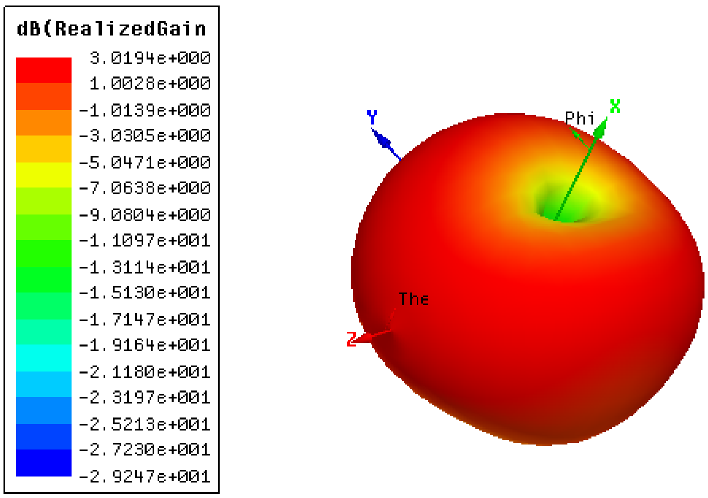

Fig 4.2: 3D Radiation Pattern of the Hexagonal Microstrip Antenna with Gain of 3.0194dB

4.1.3. S Parameters

Fig 4.3: Return loss of -25.8595dB at Resonant Frequency of 3GHz

4.1.4. Voltage Standing Wave Ratio

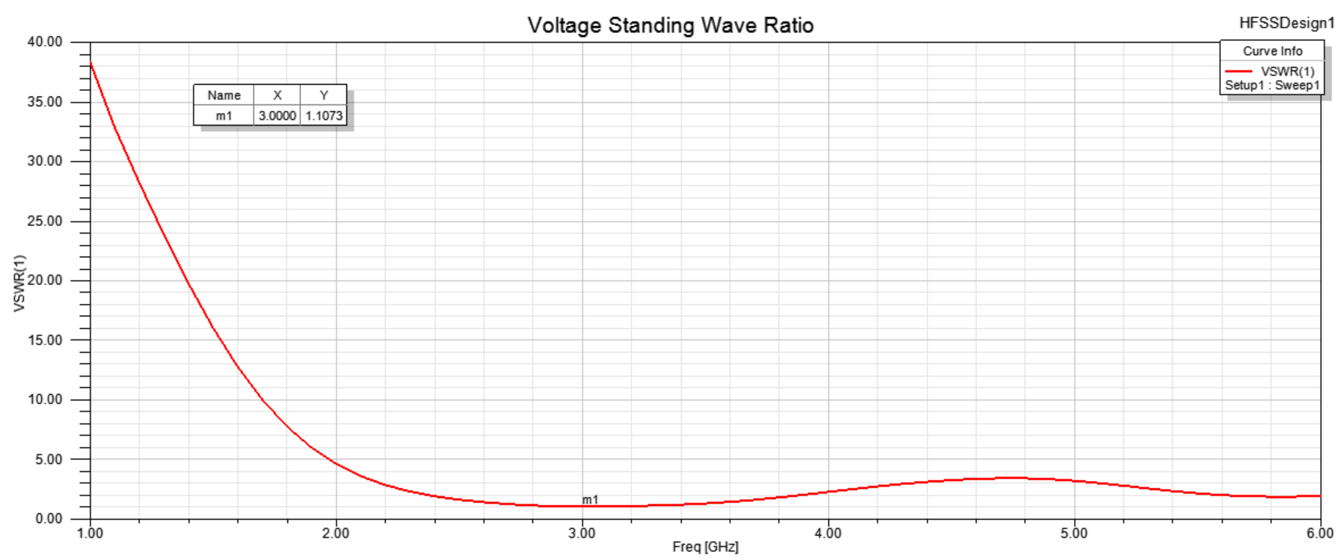

Fig 4.4: VSWR at Resonant Frequency of 3GHz is 1.1073

4.1.5. Realized Gain

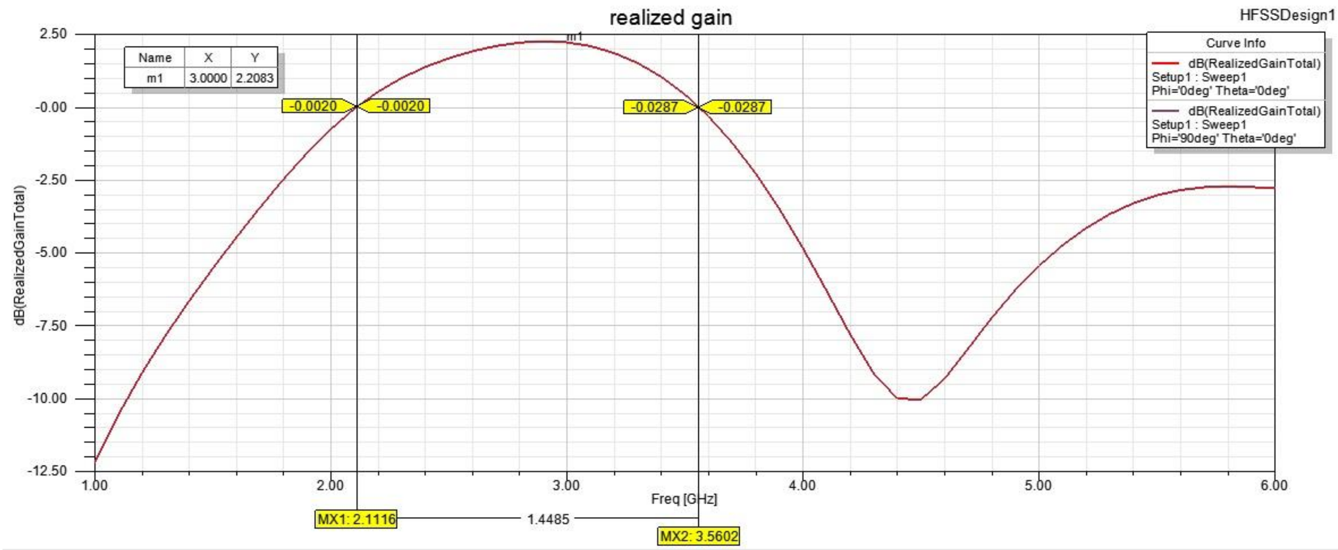

Fig 4.5: Realized Gain of 2.2083dB at Resonant Frequency of 3GHz

4.1.6. Directivity

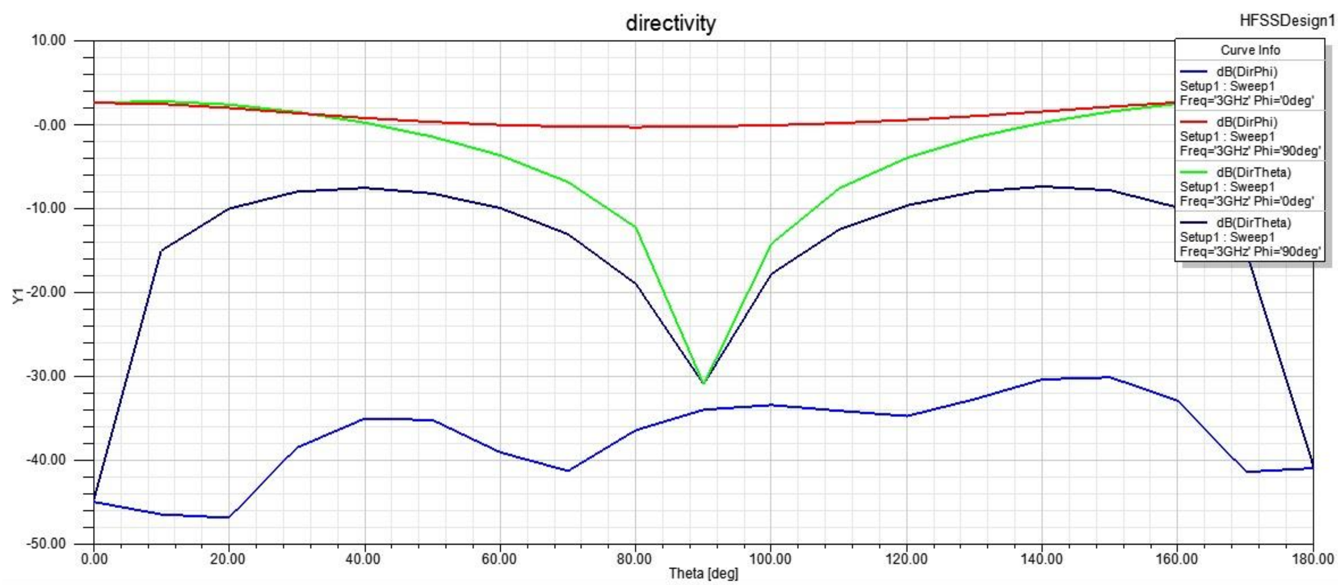

Fig 4.6: Radiation Pattern for Different Antenna Alignments

4.1.7. Current Distribution

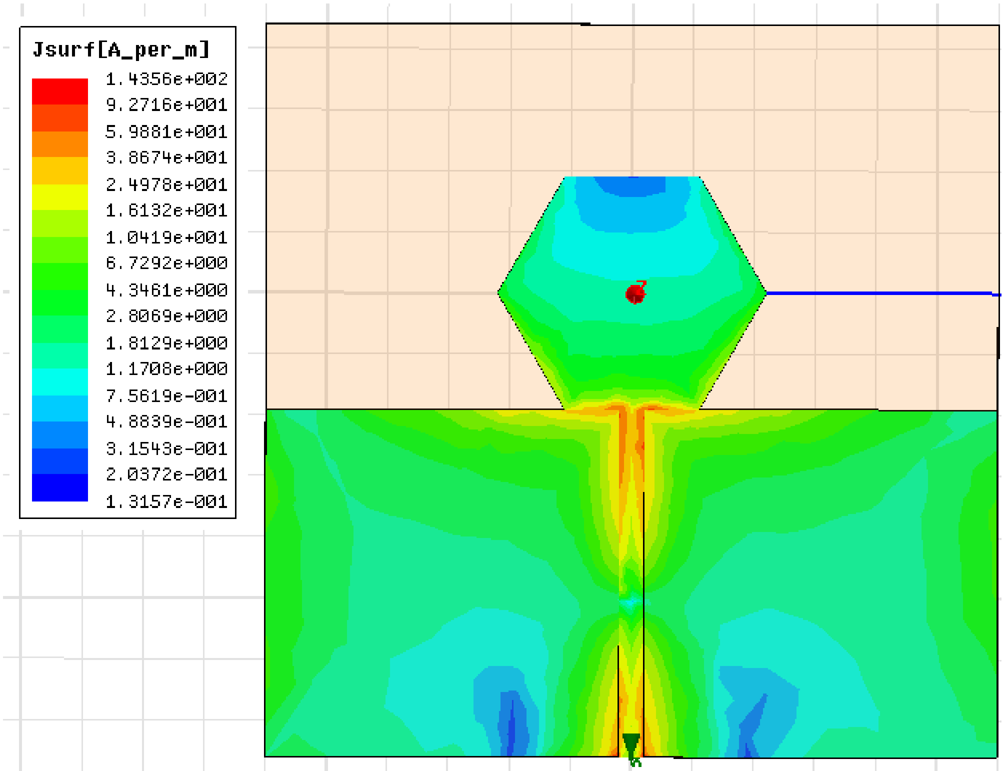

Fig 4.7: Current Distribution Field for the Hexagonal Microstrip Antenna

4.1.8. Radiation Efficiency

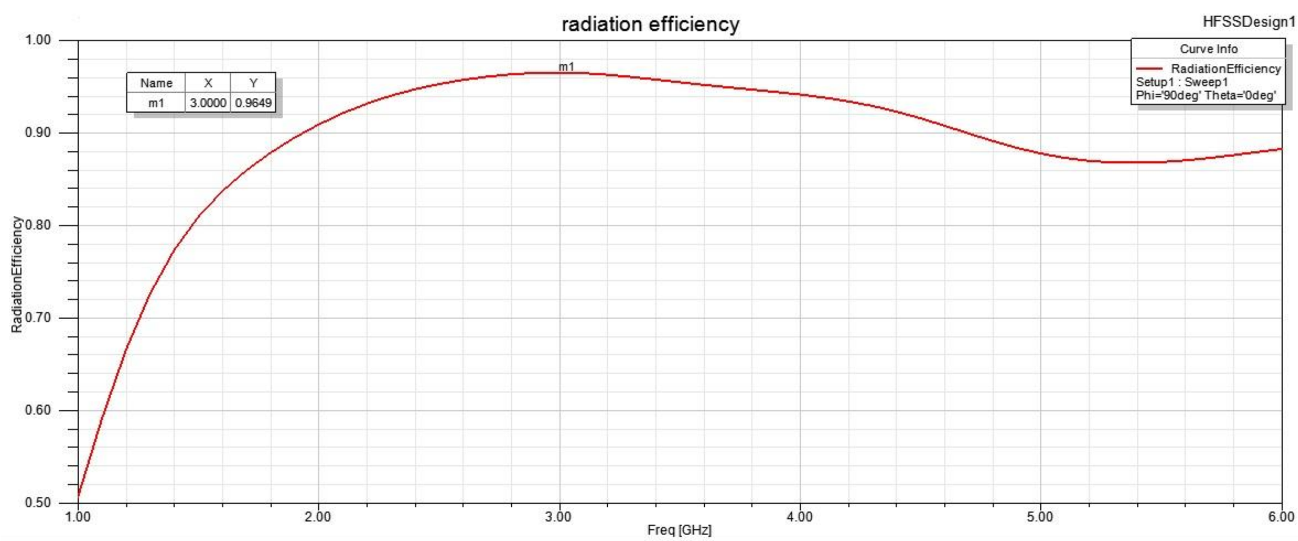

Fig 4.8: Radiation Efficiency at Resonant Frequency of 3GHz is 96%

4.2. OVERVIEW OF SIMULATED PLOTS

- Return loss at 3GHz: -25.8595dB
- 3D Polar Plot Gain: 3.0194dB (Omnidirectional Pattern)
- Voltage Standing Wave Ratio: 1.1073
- Realized Gain at 3GHz: 2.2083dB
- Radiation Efficiency: 96% efficient

CONCLUSION

The design, analysis and scope of Hexagonal Microstrip Patch Antenna for S-band has been analyzed. The reason for selecting a hexagonal shaped antenna has been discussed. A hexagonal microstrip antenna with microstrip line feed on FR 4 substrate has been designed and simulated using HFSS software. Some important parameters such as return loss, gain, radiation pattern, voltage standing wave ratio, realized gain, radiation efficiency and current distribution were observed to measure the performance of the antenna in the given band. The antenna is found to be operable within 2.4 GHz to 3.8 GHz frequency with an omnidirectional radiation pattern in YZ plane. The best performance of the antenna is observed at resonant frequency of 3GHz.

FUTURE SCOPE

Gain and Return Loss of the Hexagonal Microstrip Patch Antenna can be increased by implementing antenna array, increasing height of the substrate or by cutting of slots on the radiating patch of the antenna. This method of increasing substrate height can also be implemented with different feeding techniques. Bandwidth of the antenna can be increased by doing modifications in the dimensions of the ground plane of the antenna.

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