Performance Analysis of Rectangular and Circular Patch Antenna using HFSS

Submitted by

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A project submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in Electronics and Telecommunication Engineering

Department of Electronics and Communications Engineering

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Dhaka, Bangladesh

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Declaration

We, strongly, declare that this project has been done by us and it has not been submitted elsewhere for any degree or diplomas.

Countersigned   Signature of the students

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Approval

The project report entitled "Performance Analysis of Rectangular and Circular Patch Antenna using HFSS'' submitted by Md. Rubel Akanda, ID No: 2010-2-55-002 & Mehraj Kazi Himon, ID No: 2010-2-55-009, to the Department of Electronics & Communication Engineering, East West University, has been accepted as satisfactory for the partial fulfillment of the requirements for the degree of Bachelor of Science in Electronics and Telecommunications Engineering and approved as to its style and contents.

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ABSTRACT

In this paper presents the design and simulation of Rectangular Micro strip Patch Antenna and Circular Micro strip Patch Antenna. This Antenna will provide the wide bandwidth by introducing in to rectangular patch. The antenna design is simulated using HFSS software. The performance of the designed antenna was analyzed in terms of bandwidth, gain, return loss, VSWR and radiation pattern (3D). Dielectric Substrate Rogers RT/duroid 6002™ and Rogers RT/duroid 5880™ having dielectric constant of 2.94 and 2.2 are used. This antenna design is simulated using HFSS simulator (High Frequency Structure Simulator). The antenna is able to operate at 7.5 GHz frequency band.

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Chapter 1

Fundamental of antenna

1.1 Introduction

In this chapter we will learn the basic fundamentals of antennas. The word antenna is a key module of any wireless and Radio communication system is a device that has an ability of transmission and reception of electromagnetic energy. According to IEEE standard definitions of terms for antenna (IEEE Std145-1983) defines antenna as a way of radiating or receiving radio waves[1]. More broadly, antenna at the transmitting end transforms the information signal into an electromagnetic energy and transmits it via free space as a source of medium and at the receiving side the electromagnetic wave is received as a result information signal by conversion process is received, this treatment know how to as transducer. In erstwhile prose, it is switch from a guided wave transmission procession to unguided energy in free space ,at the receiving end the reverse process is been done devoid of intervening arrangement[1]. The frequencies for carrying this communication can be consulted from electromagnetic spectrum [1].

1.2 Patch Antenna

Microstrip patch Antennas (also just called *patchantennas*) are among the most common antenna types in use today, particularly in the popular frequency range of 1 to 6 GHz. This type of antenna had its first intense development in the 1970s, as communication systems became common at frequencies where its size and performance were very useful. At the same time, its flat profile and reduced weight, compared to parabolic reflectors and other antenna options, made it attractive for airborne and spacecraft applications. More recently, those same properties, with additional size reduction using high dielectric constant materials, have made patch antennas common in handsets, GPS receivers and

other mass-produced wireless products.Now a day, micro strip patch antennas are the most common antenna types in use. Often micro strip antennas are also referred to as patch antennas. These antennas are low-profile., comfortable to planar and non-planar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology.

In high performance applications, where size, weight, thickness, material, cost, performance ease of installation are constraints, low profile antennas may be required. Now, there are many other applications. Such as mobile radio, wireless communications, they have also similar specifications. To fulfill the requirements, micro strip patch antennas can be used. Its' frequency range is about 1~20 GHz. As the frequency is common frequency range for communication system the micro strip patch antennas are vastly used. In GPS receiver, handsets and other mass-produced wireless products, patch antennas are used.
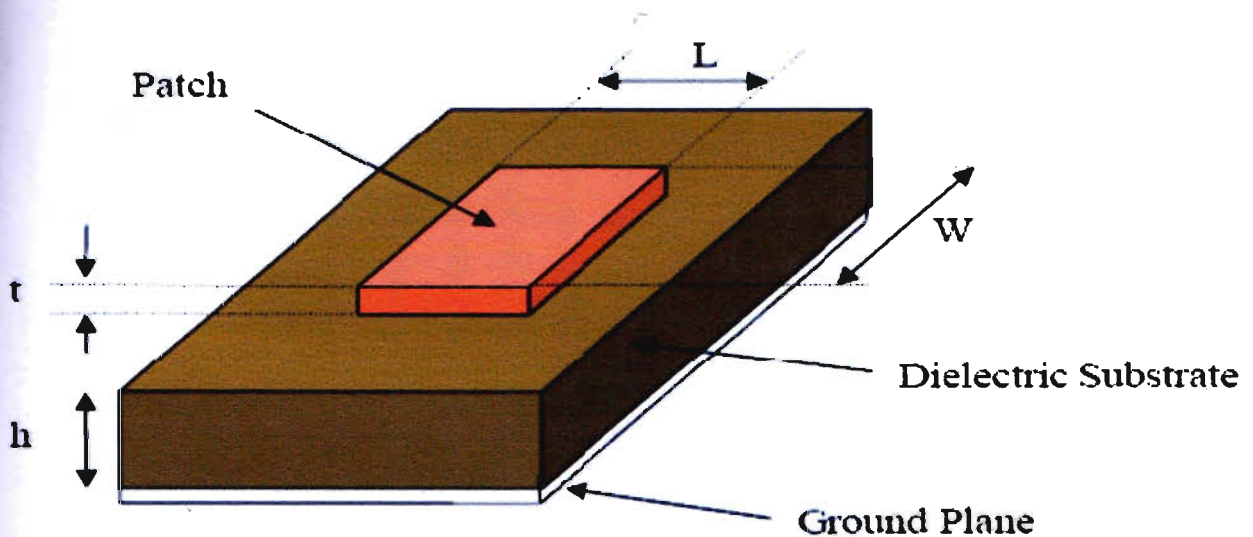
Fig.1: Microstrip Patch Antenna

Chapter 2

Architecture of Patch Antenna

2.1 Basic architecture

Micro strip patch antenna consists of radiation patch, dielectric substrate and ground plan as shown in figure 2.1.
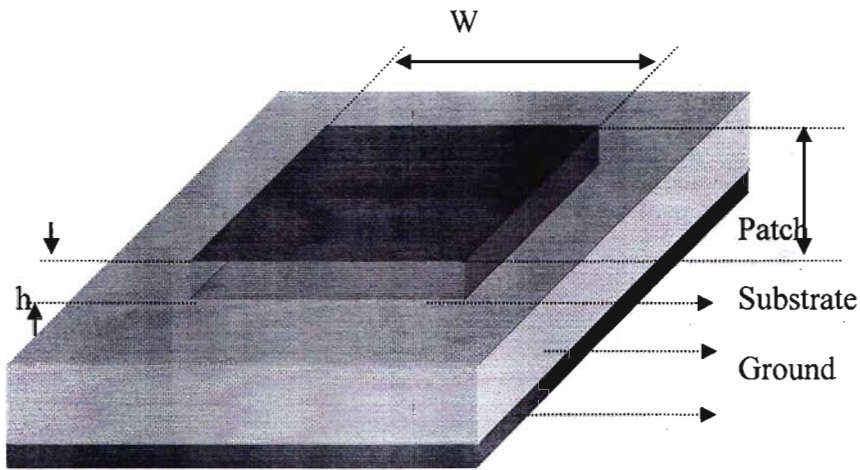
Fig 2.1: Structure of a Micro strip Patch Antenna.

The following figure shows a patch antenna in its basic architecture. The patch and the ground plane are separated by a dielectric material. A flat plate over a ground plane and then the dielectric substrate at the center and the patch is at the top. The patch and the ground plane are generally conducting materials such as gold, copper and the patch can be any shape as the design specification. The feed line is used to feed the patch. There are

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many different types of feeding techniques. Usually, the patch and the feed line are photo etched to the substrate.

The radiating patch can be square, rectangular, circular, triangular, elliptical, circular ring and dipole and so on.

Square   Rectangular Circular   Triangle

Circular ring   Dipole   Elliptical
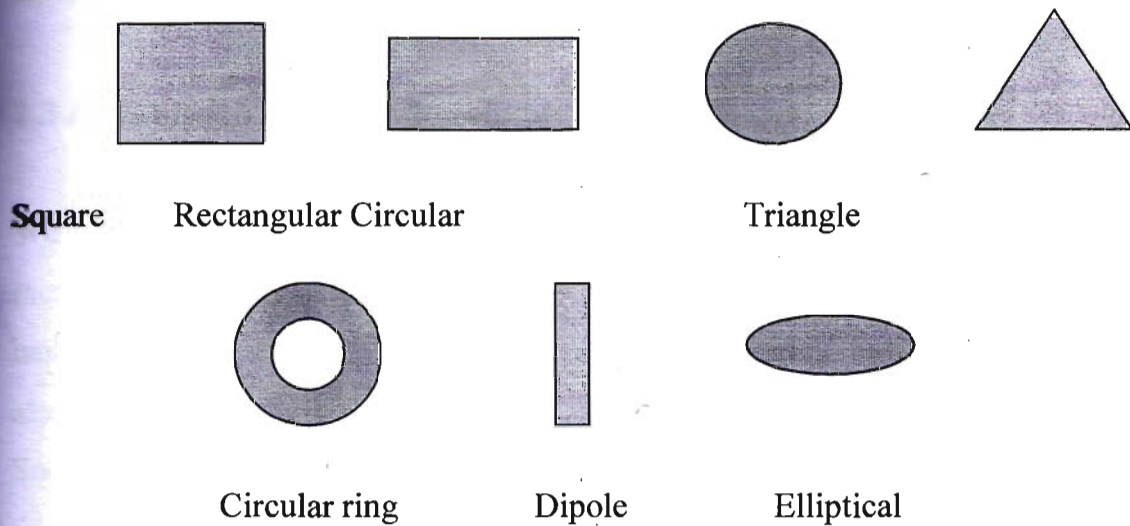
Fig 2.2: Common shapes of micro strip patch elements.

2.2 Basic Characteristics

To design the micro strip antenna for specific resonant frequency, we have to consider about the material of the patch, the dielectric constant of the substrate also the size of the patch and the substrate.

For a rectangular patch, the length, L of the patch is usually $0.3333\lambda_0 < L < 0.5\lambda_0$; where λ_0 free space wave length. The patch must be selected to be very thin such that $t << \lambda_0$; where t is the thickness of the patch. The height h of the dielectric substrate is usually

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$0.003\lambda_0 \leq h \leq 0.05\lambda_0$. [The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \leq \varepsilon_r \leq 12$]. There are many substrates that can be used for the design of the patch antennas and their dielectric constants are usually in the range of $2.2 \leq \varepsilon_r \leq 12$. Because of providing the better efficiency, larger bandwidth and better radiation, a thick dielectric constant is desirable. But this configuration provides the antenna size larger. So, thin substrates with higher dielectric constants are desirable but they are less efficient and have relatively smaller bandwidth. A compromise has to be reached between good antenna performance and circuit design.

2.3 Advantages and Disadvantages

We know antennas are used in wireless applications. Micro strip patch antennas are increasing its popularity due to its low profile. Patch antennas are exclusively used in hand held devices like GPS receivers, cell phones, pagers, radio etc. Patch antennas are also used in spacecraft, satellite and missile applications.

Some of their main advantages are:

1. high weight and small overall volume/dimension,
2. possibility of printing on curved surfaces to make conformal antennas,
3. fabrication cost is low,
4. supports both circular and linear polarization,
5. easily integrated with electric components,
6. capable of dual and triple frequency operations,
7. easily manufacturing using printed circuit technology

Some of their main disadvantages are;

1. relatively narrow frequency bandwidth,
2. low frequency,
3. low power handling capacity,
4. poor polarization purity,

5. low gain,

6. spurious feed radiation,

7. high quality factor

As micro strip patch antennas have a large quality factor, Q so the antennas are low efficiency and also narrow bandwidth. But there are low efficiency and also narrow bandwidth. But there are methods, such that the height of the substrate and that can be used to extend the efficiency and bandwidth. But as the height increases, surface waves are introduced which are not describable because given total power goes into the surface wave. The surface waves travel within the substrate and they are scattered at bends and degrade the antenna pattern and polarization characteristics. Surface waves can be eliminated while maintaining large bandwidths by using cavities. [2][3].However, the surface wave can be minimized by use of photonic band gap structures.

Chapter 3

Feed Methods

There are many techniques that can be used to feed micro strip antennas. These techniques are classified into two categories – contacting and non-contacting. In conducting technique the RF power is fed directly to the radiating patch with micro strip line. In non-conducting technique, the electromagnetic field coupling is done to transfer power between the micro strip line and the radiating patch. The four most popular are the micro stripe line feed, coaxial feed, aperture coupled feed, proximity coupled feed.

3.1 Micro strip Line Feed

Micro strip feed line is also a conducting strip, usually of much smaller width compared to the patch. The micro strip line feed is easy to fabricate, simple to match by controlling the inset position and rather simple to model. The conducting strip is directly connected to the edge of the micro strip patch. The feed line also can be etched on the same substrate to provide a planar structure. The micro strip line and the patch are impedance matched so there is no need for any additional matching elements. This is done by properly controlling the inset position. However, as the substrate thickness increases, which for practical designs limit the bandwidth of the antenna [4].
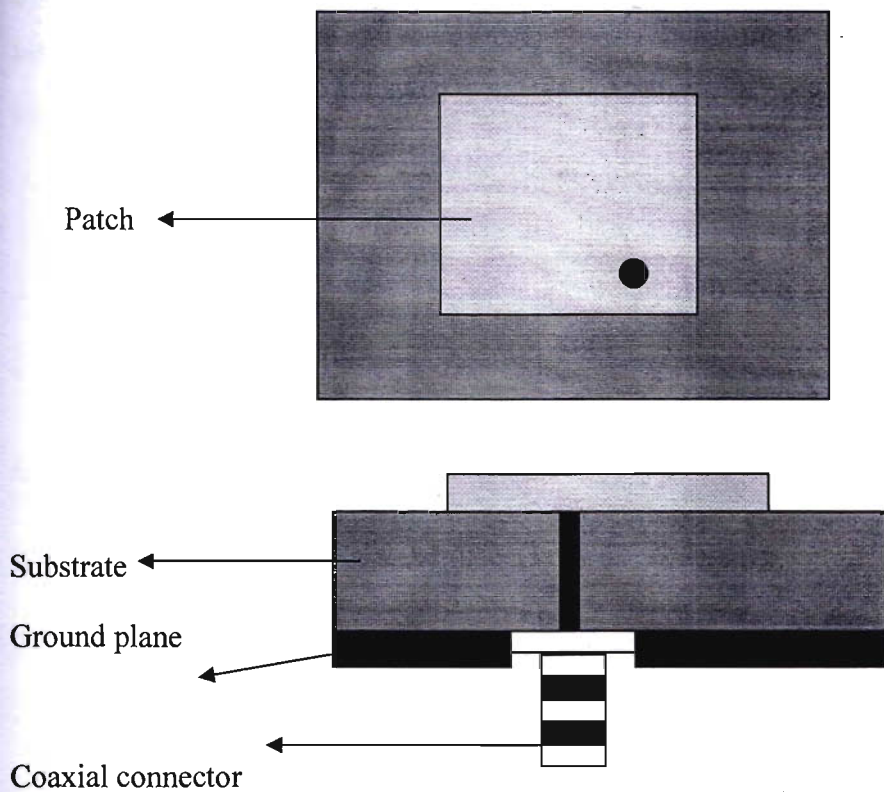
Micro Strip Feed   Patch

Substrate
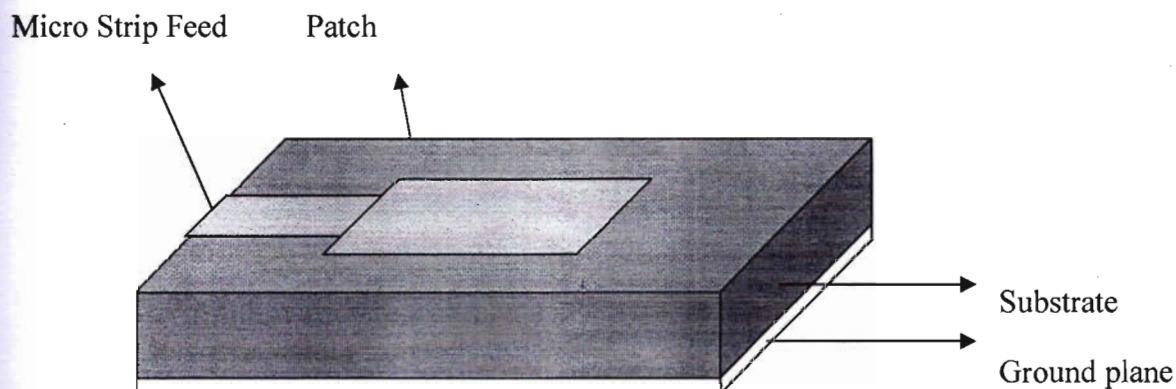
Ground plane

Fig 3.1: Micro Strip Line Feed.

3.2 Coaxial Feed Line

We know coaxial feed cable has inner conductor and outer conductor. In coaxial feed the inner conductor is connected to the radiating patch and the outer conductor is connected to the ground plane figure: 3.2. In this technique, the feed can be attached at any desired location in the radiating patch in order to match its input impedance. Coaxial feed line is also easy to fabricate and match it has low spurious radiation. However, it has narrow bandwidth and it is more difficult to model, especially for thick substrates ($h < 0.02\lambda_0$) [4].

Both the micro strip feed line and the coaxial line feed inherent asymmetries which generate higher order modes which produce cross-polarized radiation. To overcome some of these problems, non conducting aperture coupling feeds. Now we discuss the non-conducting feed techniques which have been discussed below.


Patch

Substrate

Ground plane

Coaxial connector

Fig. 3.2: Probe fed Rectangular Micro strip Patch Antenna.

3.3 Aperture Coupled Feed

In this technique, the radiating patch and the micro strip feed line are separated by the ground plane as shown in figure: 3.3. The aperture coupling consists of two substrates separated by a ground plane [4]. The radiating patch and the feed line also separated by the ground plane. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane. The coupling aperture is usually centered under the patch leading to lower cross-polarization due to symmetry of the configuration. On the bottom side of the lower substrate there is a micro stripe feed line whose energy is coupled to the patch through a slot on the ground plane separating the two substrates.

The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation pattern from 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.
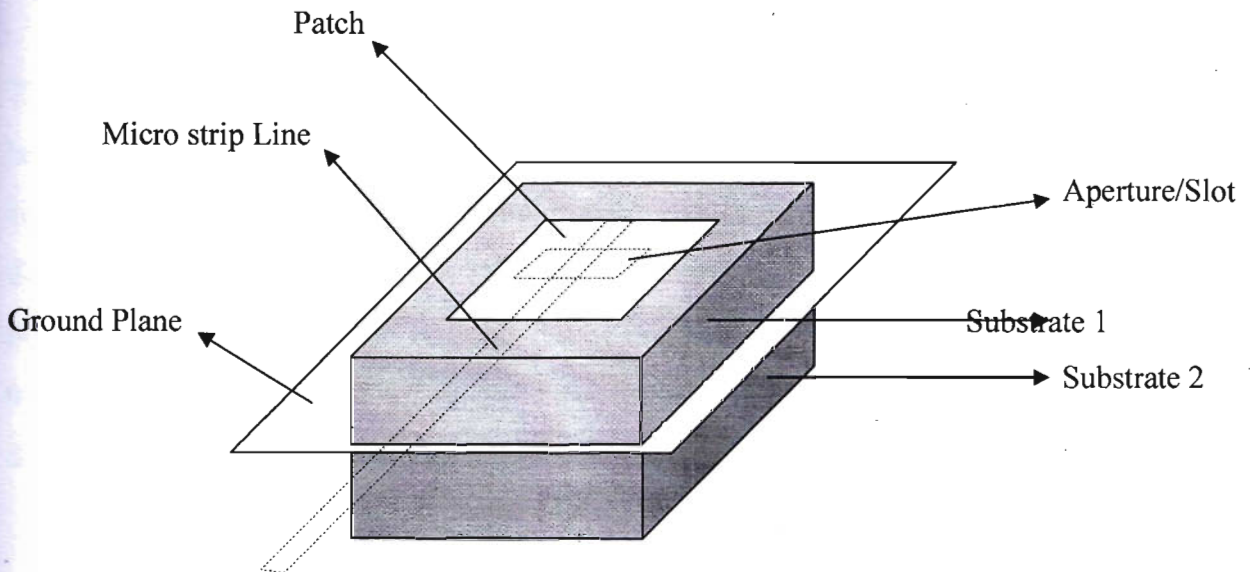
Fig. 3.3: Aperture-coupled feed.

3.4 Proximity Coupled Feed

Proximity coupled feed is also called electromagnetic coupling and it is also non-conducting feed technique. Similar to aperture coupled feed, in this technique, there are two substrates. The feed line is between the two substrates and the patch is the top of the substrate, as shown in the figure: 3.4.
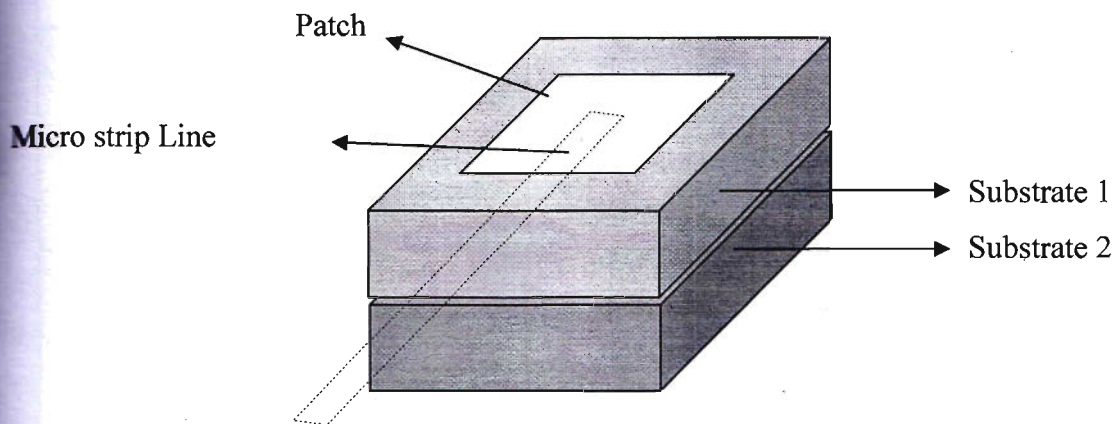
Fig. 3.4: Proximity-coupled Feed.

The main advantage of this technique is that it has low spurious radiation and it has the largest bandwidth (as high as 13%) [4][5]. As 2 substrates are used, the thickness of the antenna is increased. This technique 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 feeding stub and to control the match [6]. Though, the fabrication of the two dielectric layers, need proper alignment but it is easy to model.

Table 3.1 : Comparing the different feed techniques

| Characteristics	Micro strip 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%	13%

Chapter 4

Methods of Analysis

There are many methods of analysis for patch antenna, they are transmission line model [7] [8], cavity model and full wave model [9] [10].The transmission line model is the easiest of all, it gives good physical insight, but it is less accurate and it is more difficult to model coupling. Compare to transmission line model, the cavity model is more accurate but it is more complex [11] [12] [13]. The full wave models are extremely accurate, versatile and can treat single elements, finite and arrays, stacked elements, arbitrary shaped elements and coupling. However, they are most complex models and usually give less physical insight.

4.1 Transmission Line Model

We know that the transmission line model is the easiest of all but if yields the least accurate results. This model represents the micro strip antenna by two slots of width, W and height h, separated by transmission line of length, L. This is a nonhomogenous line of two dielectrics, typically the air and substrate.

Strip Conductor

Dielectric Substrate

Ground Plane

h
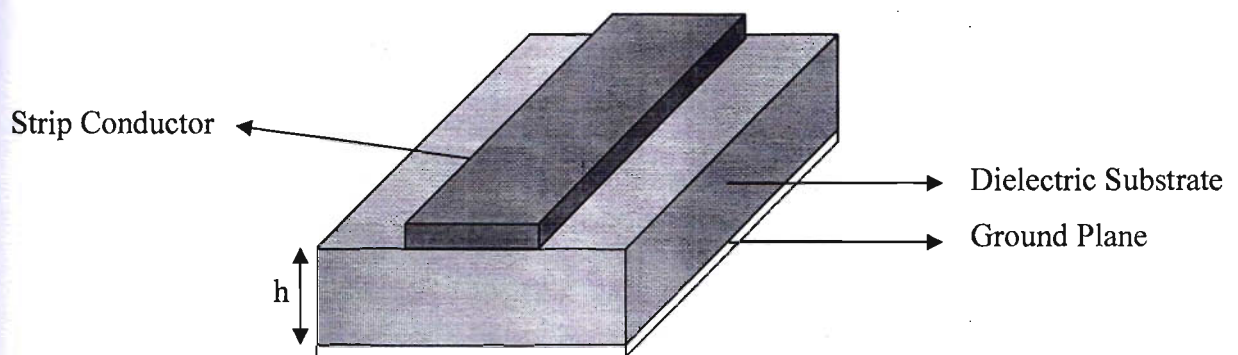
Fig 4.1: Micro strip Line.
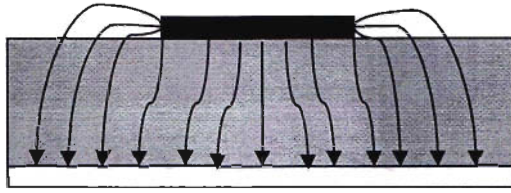
Fig. 4.2: Electric Field Lines.

From the figure: 4.2we see that most of the electric field lines reside in the substrate and parts of some lines exist in the air. As $L/h \gg 1$ and $\varepsilon_r \gg 1$, the electric field lines concentrates mostly in the substrate. For this reason, this transmission-magnetic (TEM) mode of transmission, since the phase velocities would be dimension of the patch are finite along the length and width, the fields at the edges of the patch undergo fringing since some of the waves travel and some in air, an effective dielectric constant ε_{reff} is introduced to account for fringing and the wave propagation in the line. The value of ε_{reff} is slightly less than ε_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air as shown in figure: 4.2. The expression for ε_{reff} is given by Balanis as: [14]

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h}{W}]^{-\frac{1}{2}}$$
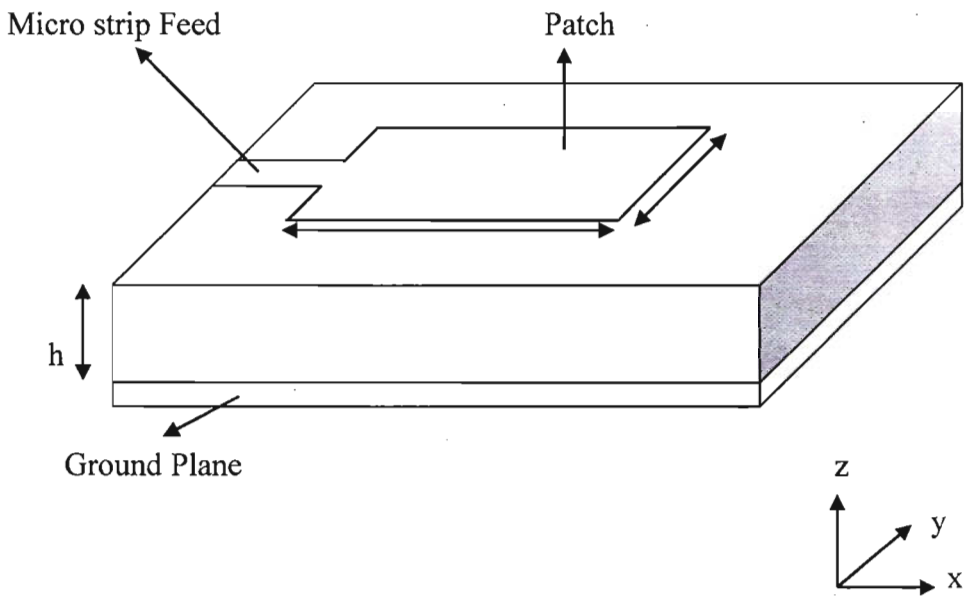
Where, ε_{reff} = Effective dielectric constant

ε_r = Dielectric constant of the substrate

h = Height of dielectric substrate

W = Width of the patch

Fig. 4.3: Micro strip Patch Antenna.

Consider, from the above figure: 4.3, which shows a rectangular patch antenna of length L, width W resting on a substrate of height h. The co-ordinate axis is selected such that the length is along the x direction; width is along the y direction and the height is along the z direction. In order to operate in the fundamental dominant TM_{10} mode, the length of the patch must be slightly less than $\lambda/2$ where λ is the wave length in the dielectric medium and equal to $\lambda_0 / \sqrt{e_{reff}}$; where λ_0 is the free space wave length.

The TM_{10} mode implies that the field varies are $\lambda/2$ cycle along the length, and there is no variation along the width of the patch. From the figure 4.4, the micro strip patch antenna is represented by two slots, separated by a transmission line of length L and open circuited at both the ends. Along the width of the patch, the voltage is maximum and the current is minimum due to the open ends. The fields at the edges can be resolved into normal and tangential comparatives with respect to the ground plane.

Radiating Slot   Ground Plane

L

W

ΔL

Ey

Ex
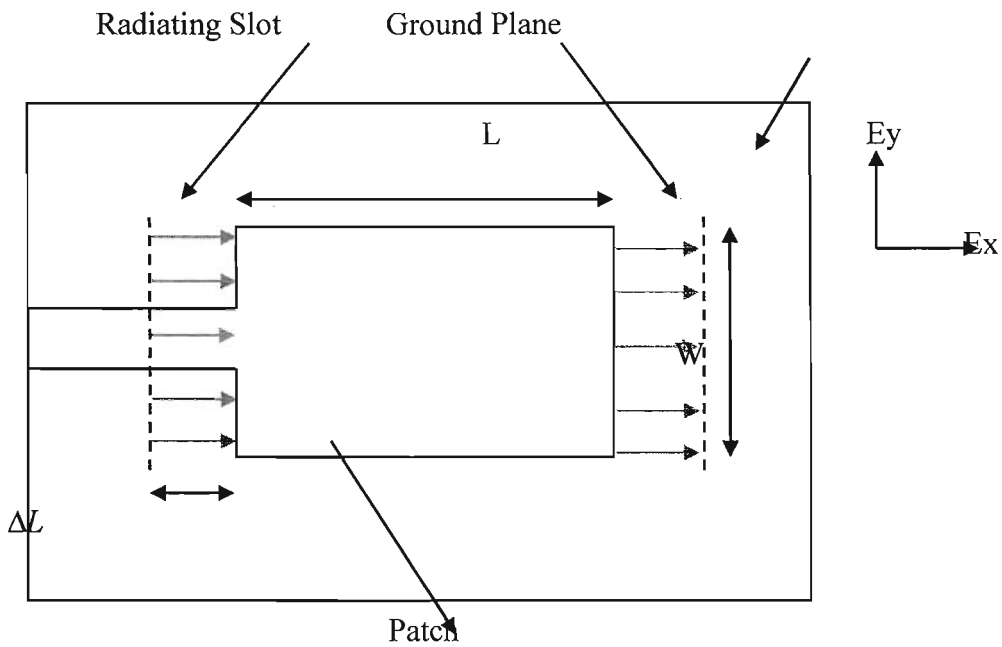
Patch

Fig. 4.4: Top View of Antenna.

h
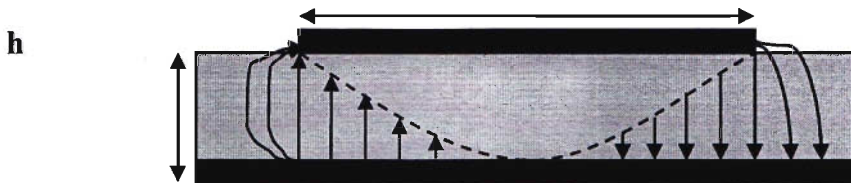
Fig. 4.5: Side View of Antenna.

It is shown from the figure: 4.5that the normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase since the patch is $\lambda/2$ long and have they canceled each other in the both side directions. The tangential components which are in phase means that the resulting field combines to give maximum radiated field normal to the surface. Hence, the edges along the width can be represented as two radiating slots, which are $\lambda/2$ apart and excited in phase and radiating in the half space about the ground plane. The fringing fields along the width can be modeled as

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radiating slots and electrically the patch of the micro strip antenna looks greater than its physical dimensions.

The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is given empirically by Hammerstad [15],

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

Since the length of the patch has been extended by ΔL on each side, the effective length of the patch is now

$$L_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{reff}}}$$

For a rectangular micro strip patch antenna, the resonant frequency for any TM_{mn} mode is given by James and Hall [16] as:

$$f_0 = \frac{c}{2\sqrt{\varepsilon_{reff}}} \left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2 \right]^{\frac{1}{2}}$$

Where m and n are modes along L and W respectively, for efficient radiation, the width W is given by Bahl and Bhartia [17] as

$$W = \frac{c}{2 f_0 \sqrt{\frac{(\varepsilon_r + 1)}{2}}}$$

4.2 Antenna Parameters

Antenna parameters are used to characterize performance of an antenna when designing and measuring antennas. In this Section, terms like bandwidth, radiation pattern, gain, polarization, input impedance are explained.

4.2.1 Bandwidth

The properties of input impedance, polarization, gain of an antenna do not necessary vary in the same manner moreover there is no distinctive characterization of the bandwidth. To calculate percentage of bandwidth:

% of BW= $(f_2 - f_1)/f_0$ *100%

4.2.2 Radiation Pattern

The radiation pattern of microstrip Patch Antenna is the power radiated or received by the antenna. It is the function of angular position and radial distribution from the antenna.

4.2.3 Return Loss

Power will not deliver to the load and is a return of the power, that is called loss, and this loss that is returned is called the return loss. Larger return loss indicates higher power being radiated by the antenna which eventually increases the gain.

$$RL = 10 \log_{10} \frac{P_{in}}{P_{ref}} \ (dB)$$

4.2.4 Directivity

"The ratio of the radiation intensity in a prearranged direction from the antenna to the radiation intensity averaged over all directions, the average radiation power intensity is equivalent to the radiated power by the antenna divided by 4π".

$$D = \frac{\omega}{pt/4\pi} = \frac{4\pi|E(r)|^2}{\int|E(r)|^2\, d\Omega}$$

4.2.5 Gain

The ratio of the power radiated or received by meticulous antenna in a prearranged direction, to the power radiated or received by a taking reference ideal isotropic antenna in cooperation fed by the similar power. Due the isotropic as ideal antenna we take in dBi as reference unit.

4.2.6 Input Impedance

The input impedance of an antenna is defined as "the impedance presented by an antenna at its terminals or the ratio of the voltage to the current at the pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point".

4.2.7 Voltage Standing Wave Ratio (VSWR)

The VSWR is an important specification for all communication devices. It measures how well an antenna is matched to the cable impedance.

Chapter5

Introduction to HFSS

HFSS is a high-performance full-wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment where solutions to your 3D EM problems are quickly and accurately obtained. Ansoft HFSS employs the Finite Element Method (FEM), adaptive meshing, and brilliant graphics to give you unparalleled performance and insight to all of your 3D EM problems. Ansoft HFSS can be used to calculate parameters such as S Parameters, Resonant Frequency, and Fields.

5.1 HFSS USES

Typical uses include:
- **Package Modeling**

BGA, QFP, Flip-Chip.
- **PCB Board Modeling**

Power/Ground planes, Mesh Grid Grounds, Backplanes.
- **Silicon/GaAs**

Spiral Inductors, Transformers.
- **EMC/EMI**

Shield Enclosures, Coupling, Near- or Far-Field Radiation
- **Antennas/Mobile Communications**

Patches, Dipoles, Horns, Conformal Cell Phone Antennas, Quadrafilar Helix, Specific Absorption Rate(SAR), Infinite Arrays, Radar Cross Section(RCS), Frequency Selective Surfaces(FSS).
- **Connectors**

Coax, SFP/XFP, Backplane, Transitions.
- **Waveguide**

Filters, Resonators, Transitions, Couplers.
- **Filters**

Cavity Filters, Microstrip, Dielectric.

HFSS is an interactive simulation system whose basic mesh element is a tetrahedron. This allows you to solve any arbitrary 3D geometry, especially those with complex curves and shapes, in a fraction of the time it would take using other techniques.

The name HFSS stands for High Frequency Structure Simulator. Ansoft pioneered the use of the Finite Element Method (FEM) for EM simulation by developing/implementing technologies such as tangential vector finite elements, adaptive meshing, and Adaptive Lanczos-Pade Sweep (ALPS). Today, HFSS continues to lead the industry with innovations such as Modesto-Nodes and Full- Wave Spice™.

Ansoft HFSS has evolved over a period of years with input from many users and industries. In industry, Ansoft HFSS is the tool of choice for high-productivity research, development, and virtual prototyping.

5.2 Getting Help

If you have any questions while you are using Ansoft HFSS you can find answers in several ways:

5.2.1 Ansoft HFSS Online Help

Provides assistance while you are working.

• To get help about a specific, active dialog box, click the Help button in the dialog box or press the F1 key.

• Select the menu item Help > Contents to access the online help system.

• Tooltips are available to provide information about tools on the toolbars or dialog boxes. When you hold the pointer over a tool for a brief time, a tooltip appears to display the name of the tool.

• As you move the pointer over a tool or click a menu item, the Status Bar at the bottom of the Ansoft HFSS window provides a brief description of the function of the tool or menu item.

• The Ansoft HFSS Getting Started guide provides detailed information about using HFSS to create and solve 3D EM projects.

5.2.2 Ansoft Technical Support

1. To contact Ansoft technical support staff in your geographical area, please log on to the Ansoft corporate website, ansoft.com and select Contact.

o Your Ansoft sales engineer may also be contacted in order to obtain this information.

5.2.3 Visiting the Ansoft Web Site

If your computer is connected to the Internet, you can visit the Ansoft Web site to learn more about the Ansoft company and products.

2. From the Ansoft Desktop
o Select the menu item Help >Ansoft Corporate Website to access the Online Technical Support (OTS) system.
3. From your Internet browser
o Visit ansoft.com

5.2.4 For Technical Support

The following link will direct you to the Ansoft Support Page. The Ansoft Support Pages provide additional documentation, training, and application notes [18].

5.3 Ansoft Terms

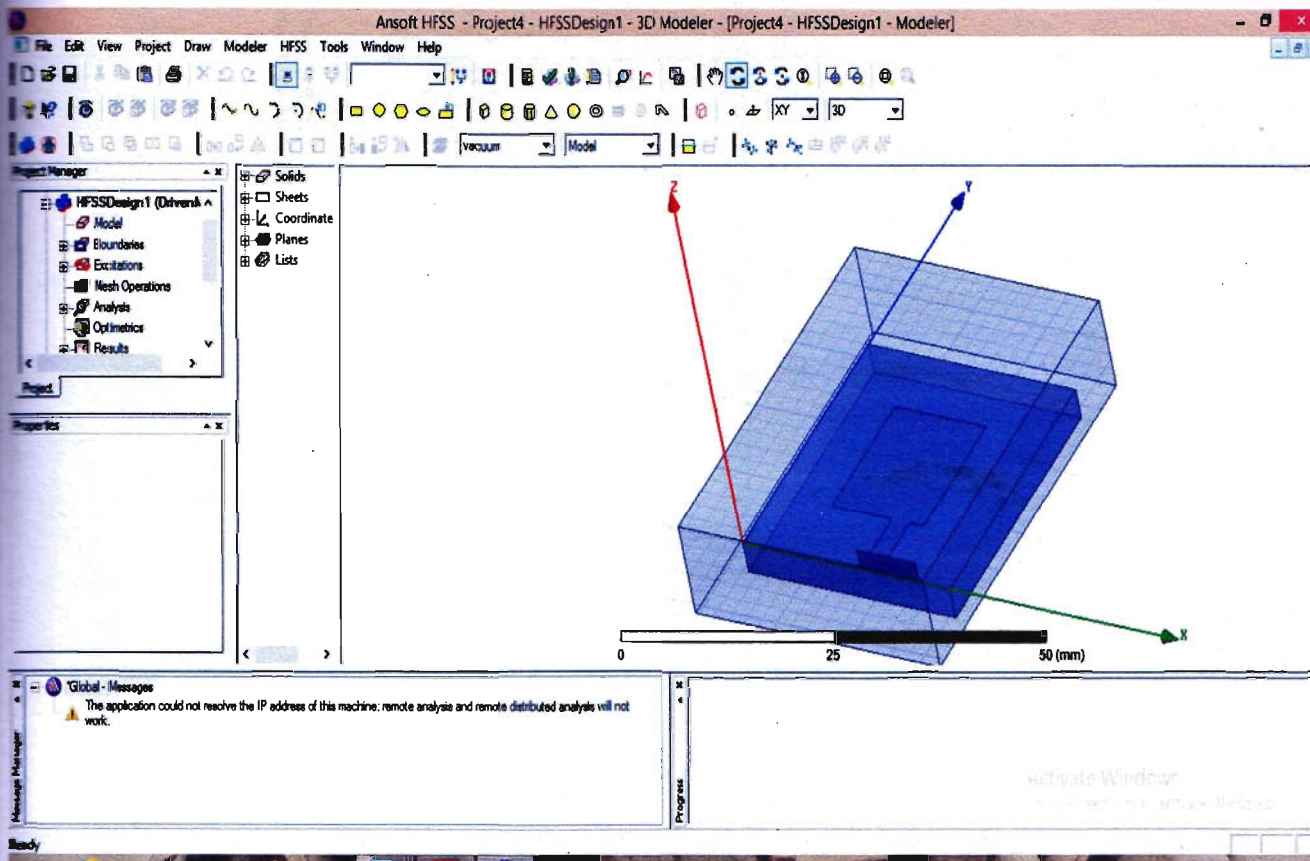The Ansoft HFSS window has several optional panels:
i. Project Manager
ii. Message Manager
iii. Property Window
iv. Progress Window
v. 3D Modeler Window

These above managers and windows are shown in Fig. and their details are given in coming sections

Fig.5.1:Ansoft HFSS window.

5.3.1 Project Manager

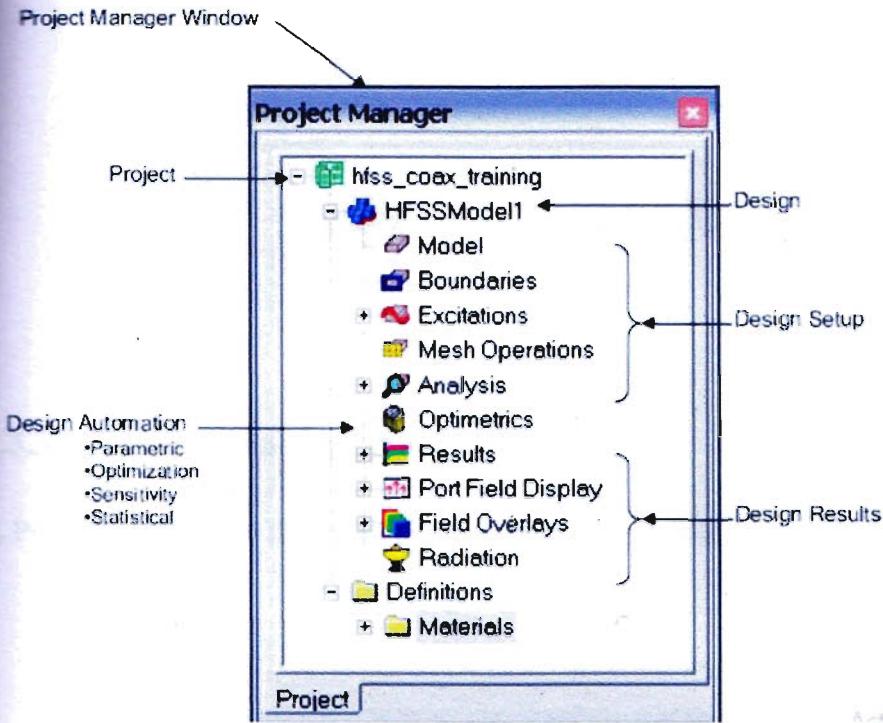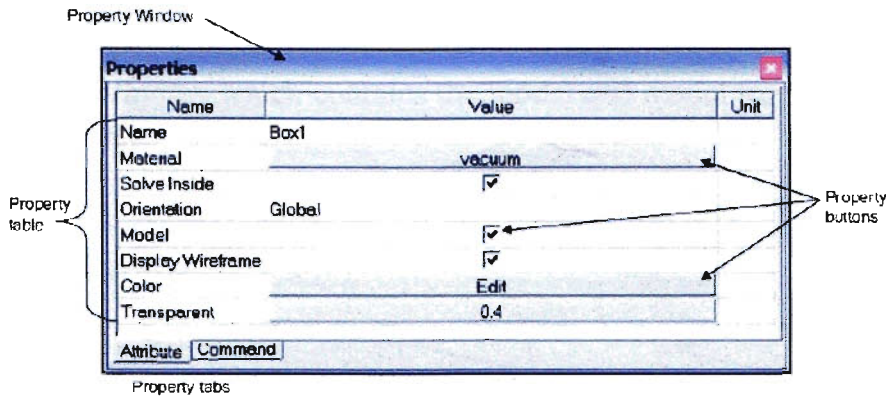A Project Manager which contains a design tree which lists the structure of the project is shown in Fig 5.2

Fig 5.2: Ansoft HFSS Project Manager.

5.3.2 Message Manager

A Message Manager that allows you to view any errors or warnings that occur before you begin a simulation is shown in Fig. 5.3
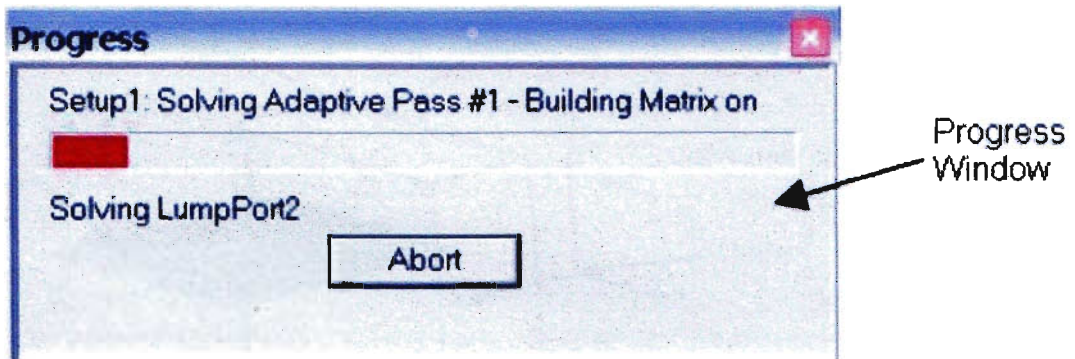
Fig 5.3: Ansoft HFSS Property Window.

5.3.3 Progress Window

A Progress Window that displays solution progress is shown in Fig. 5.4

Fig 5.4: Ansoft HFSS Progress Window.

5.3.4 3D Modeler Window

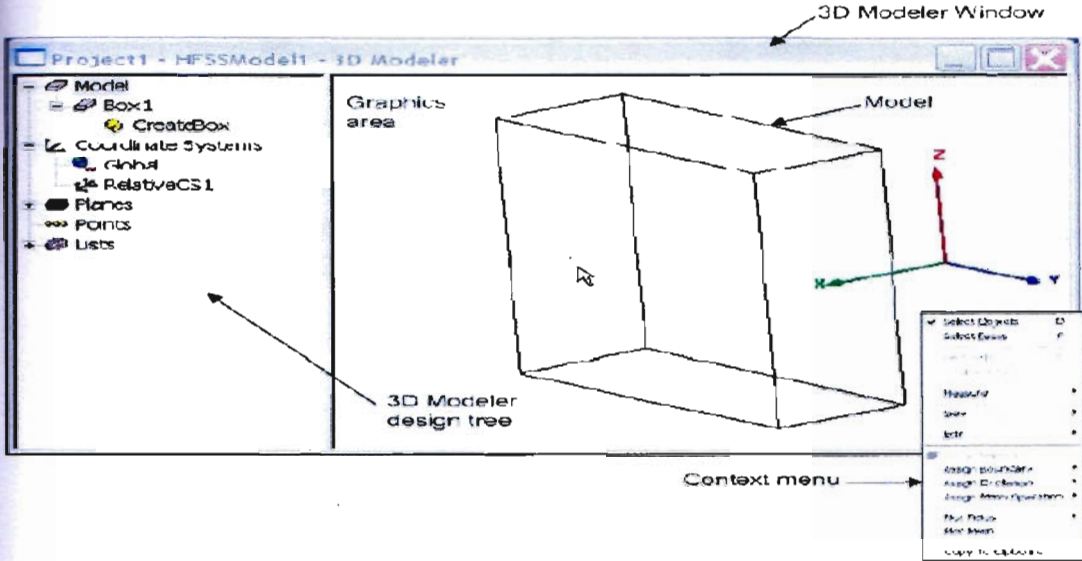A 3D Modeler Window which contains the model and model tree for the active design is shown respectively.
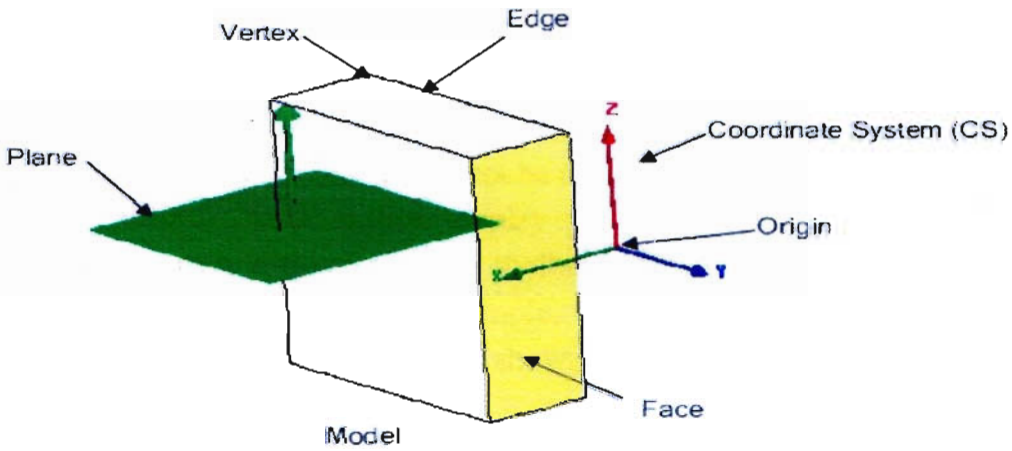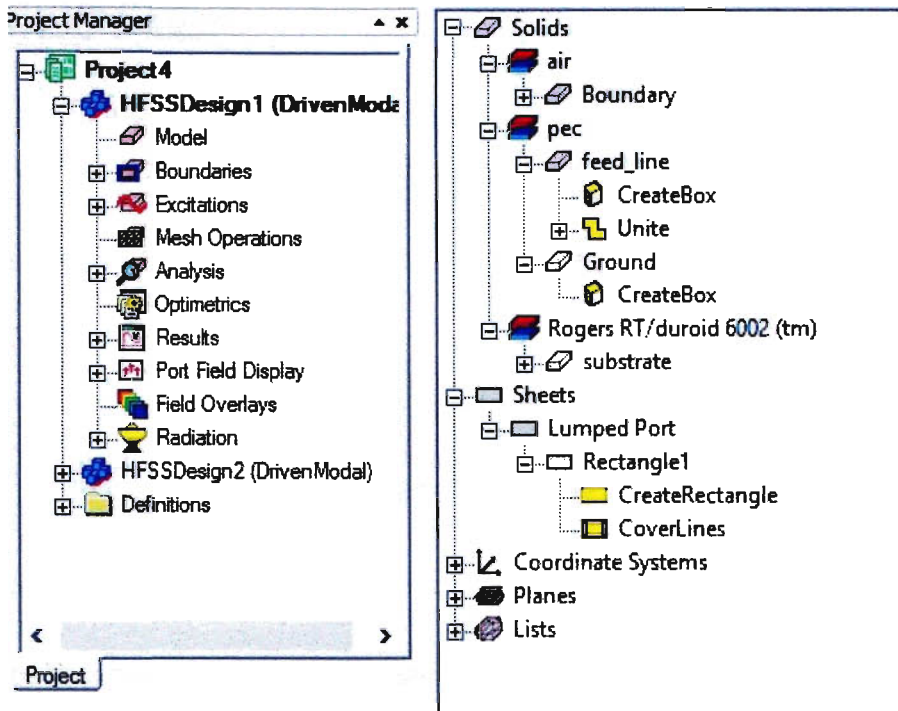

Fig 5.5: Ansoft HFSS 3D Modeler Window.

Fig 5.6: Model.

Fig 5.7:3D Modeler Design Tree.

5.4 Toolbars

The toolbar buttons are shortcuts for frequently used commands. Most of the available toolbars are displayed in this illustration of the Ansoft HFSS initial screen, but your Ansoft HFSS window probably will not be arranged this way.

You can customize your toolbar display in a way that is convenient for you. Some toolbars are always displayed; other toolbars display automatically when you select a document of the related type. For example, when you select a 2D report from the project tree, the 2D report toolbar displays, as shown in Fig.5.8
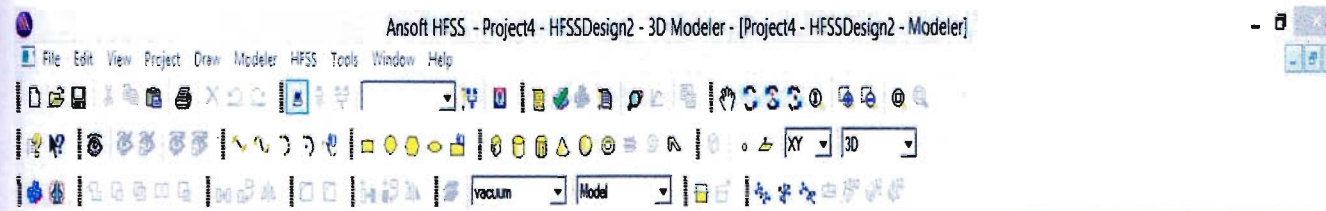
Fig 5.8: Ansoft HFSS Toolbars.

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5.5 Ansoft HFSS Desktop

The Ansoft HFSS Desktop provides an intuitive, easy-to-use interface for developing passive RF device models. Creating designs, involves the following:

i.   **Parametric Model Generation** – creating the geometry, boundaries and excitations.

ii.   **Analysis Setup** – defining solution setup and frequency sweeps.

iii.   **Results** – creating 2D reports and field plots.

iv.   **Solve Loop** - the solution process is fully automated.

To understand how these processes co-exist, examine the illustration shown In Fig.5.9
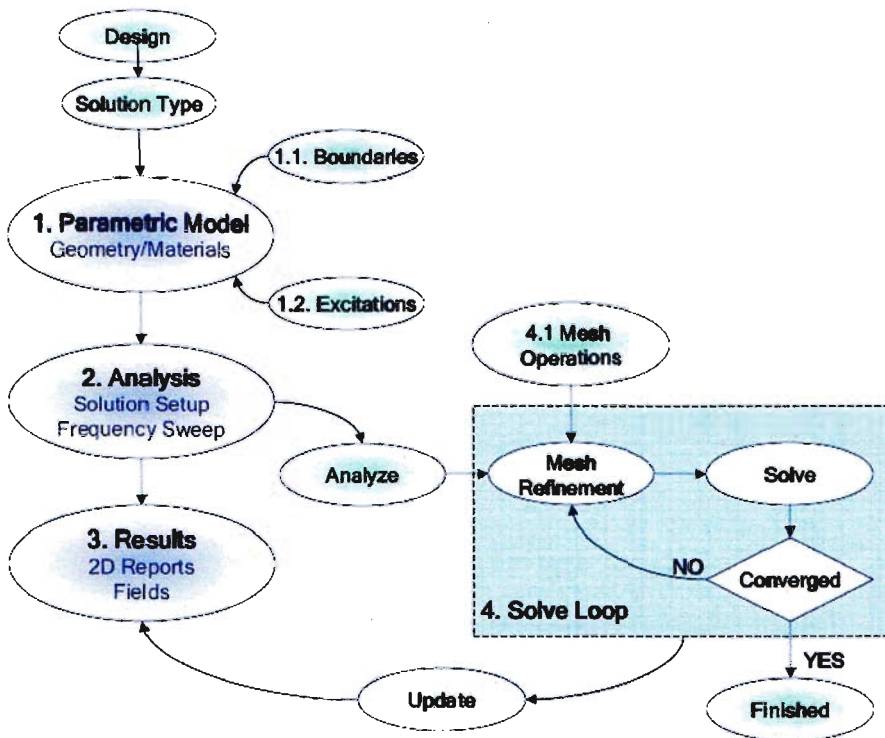
Fig 5.9: Ansoft HFSS Desktop.

5.6 Opening a HFSS project

This section describes how to open a new or existing project.

5.6.1 Opening a New project

To open a new project:
i. In an Ansoft HFSS window, select the menu item File > New.
ii. Select the menu Project > Insert HFSS Design.

5.6.2 Opening an Existing HFSS project

To open an existing project:
i. In an Ansoft HFSS window, select the menu File > Open. Use the Open dialog to select the project.
ii. Click Open to open the project

Fig 5.10: Opening a HFSS project.

5.7 Set Solution Type

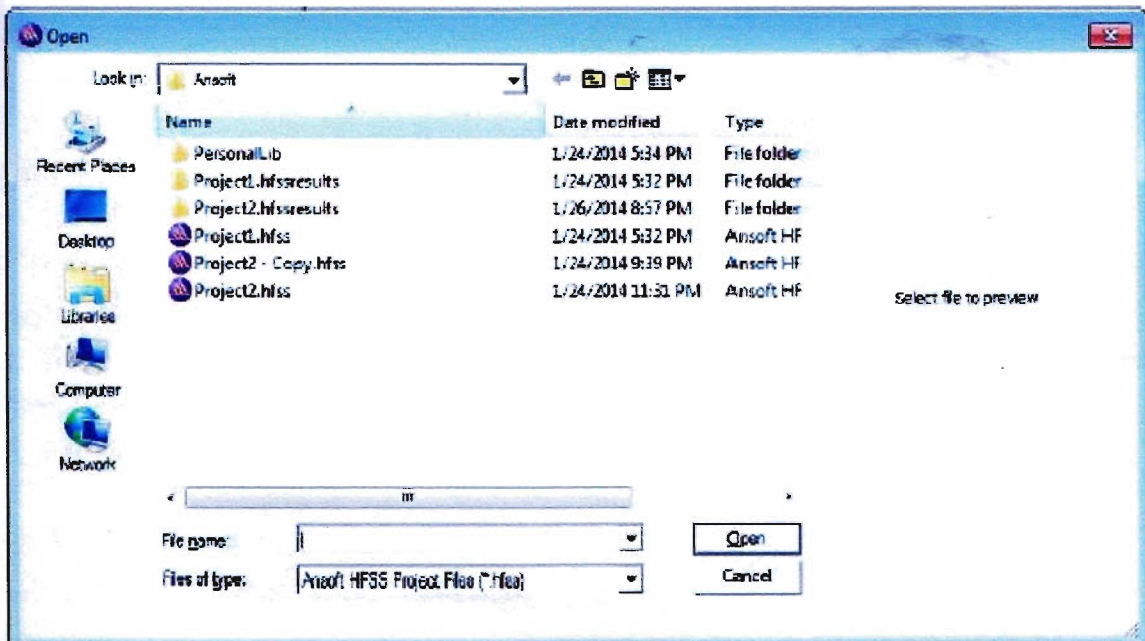This section describes how to set the Solution Type. The Solution Type defines the type of results, how the excitations are defined, and the convergence. The following Solution Types are available:

i. **Driven Modal** - calculates the modal-based S-parameters. The S-matrix solutions will be expressed in terms of the incident and reflected powers of waveguide modes.

ii. **Driven Terminal** - calculates the terminal-based S-parameters of multiconductor transmission line ports. The S-matrix solutions will be expressed in terms of terminal voltages and currents.

iii **Driven Transient** It employs a time-domain ("transient") solver. Typical applications include, but are not limited to Simulations with pulsed excitations, such as ultra-wide band antennas, lightning strikes, electro-static discharge; field visualization employing short-duration excitations; time-domain reflectometry.

iv. **Eignemode**– calculate the eigenmodes, or resonances, of a structure. The Eigenmode solver finds the resonant frequencies of the structure and the fields at those resonant frequencies

5.8 Convergence

i. **Driven Modal** – Delta S for modal S-Parameters. This was the only convergence method available for Driven Solutions in previous versions.

ii. **Driven Terminal New** – Delta S for the single-ended or differential nodal S-Parameters.
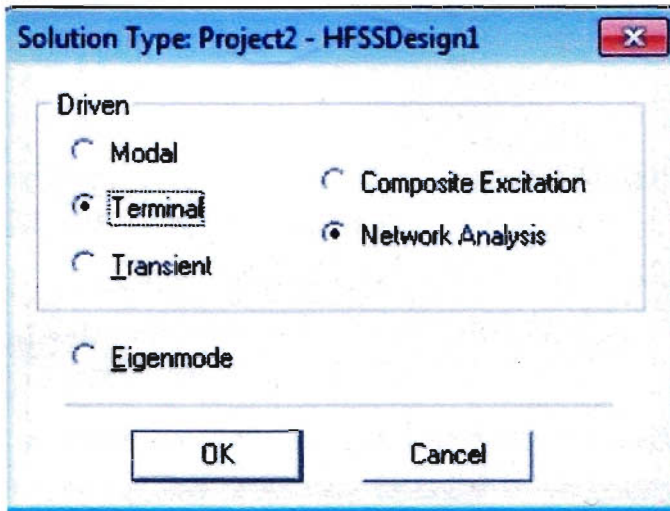
iii. **Eigenmode**- Delta F

5.9 To set the solution type:
Select the menu item HFSS > Solution Type
Solution Type Window:
• Choose one of the following:
o Driven Modal
o Driven Terminal
o Driven Transient
o Eigenmode

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• Click the OK button

Fig 5.11: Solution Type.

5.10 Parametric Model Creation

The Ansoft HFSS 3D Modeler is designed for ease of use and flexibility. The power of the 3D Modeler is in its unique ability to create fully parametric designs without editing complex macros/model history. The purpose of this section is to provide an overview of the 3D Modeling capabilities. By understanding the basic concepts outlined here you will be able to quickly take advantage of the full feature set offered by the 3D Parametric Modeler.

Chapter 6

Patch Antenna Analysis

In this analysis we use Rogers RT/duroid 6002(tm) material for the substrate. To find the acceptable gain at -10 dB. Here we took shape of the patch: (i) rectangular and (ii) circular.

6.1 RT/duroid® 6002™

Microwave material was the first low loss and low dielectric constant laminate to offer superior electrical and mechanical properties essential in designing complex microwave structures which are mechanically reliable and electrically stable. The thermal coefficient of dielectric constant is extremely low from -55°C to+150°C (-67°F to 302°F) which provides the designers of filters, oscillators and delay lines the electrical stability needed in today's demanding applications[19].
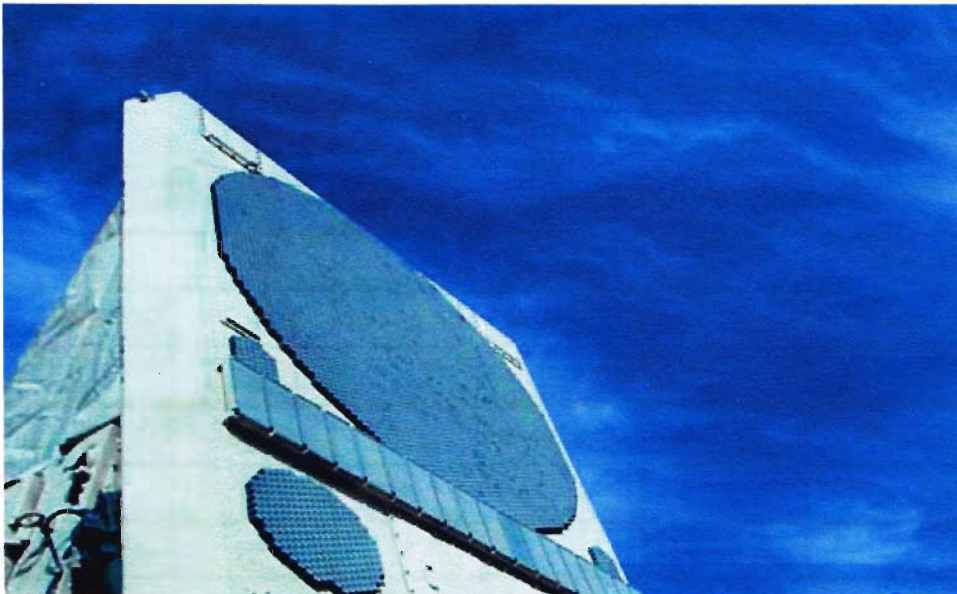
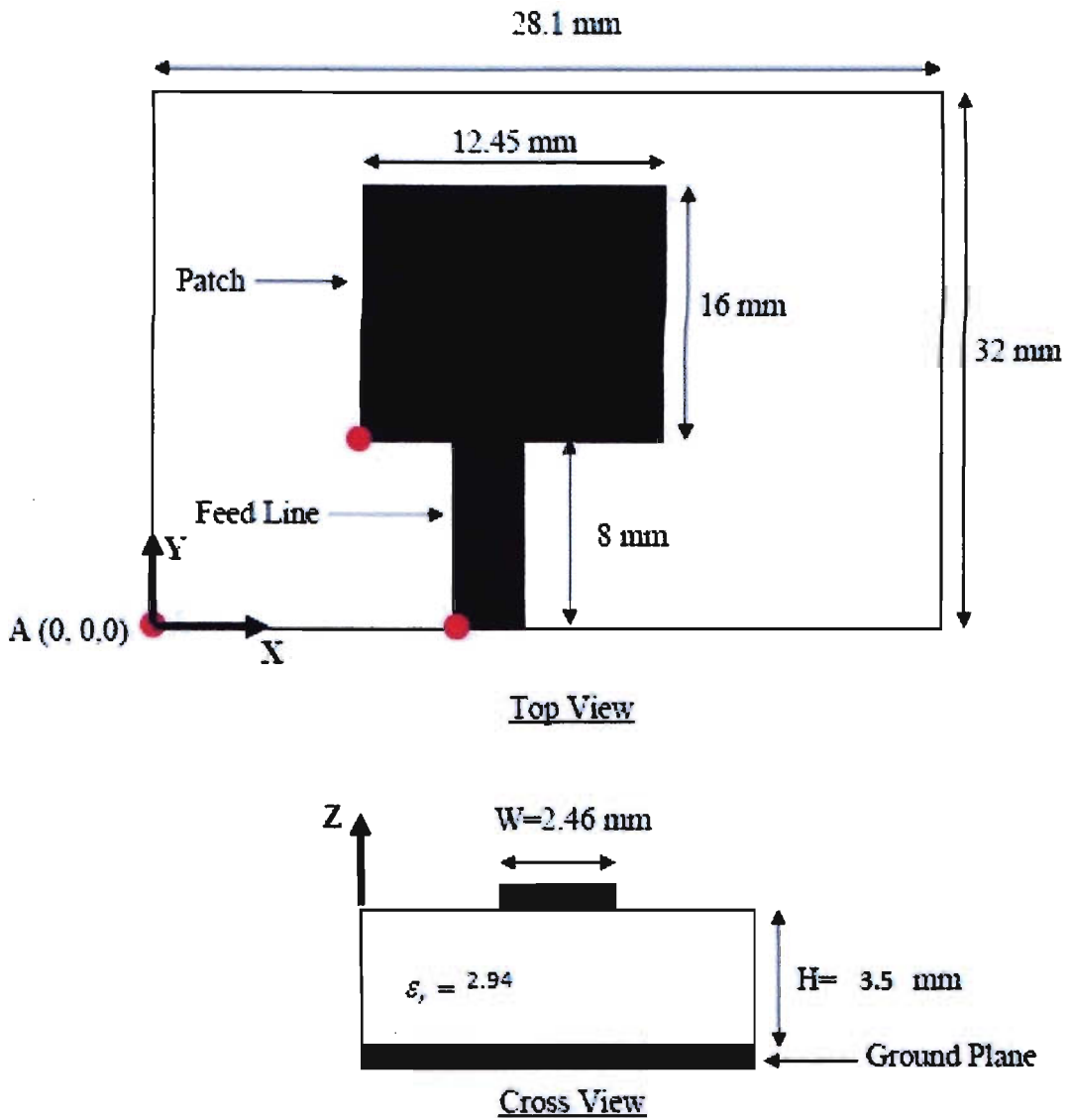

Fig 6.1: Rogers RT/duroid 6002™.

Table 6.1: Data Sheet of Rogers RT/duroid 6002™

Property	Typical Value RT/duroid 6002	Direction	Units [1]	Conditions	Test Method
Dielectric Constant, ε_r Process	2.94 ± 0.04	Z	-	10GHz/23ºC	IPC-TM-650, 2.5.5.5
Dielectric Constant, ε_r Design	2.94			8GHz-40GHz	Differential Phase Length Method
Dissipation Factor, TAN δ	0.0012	Z	-	10 GHz/23ºC	IPC-TM-650, 2.5.5.5
Thermal Coefficient of ε_r	+12	Z	ppm/ºC	10 GHz 0-100ºC	IPC-TM-650, 2.5.5.5
Volume Resistivity	10^6	Z	Mohm cm	A	ASTM D257
Surface Resistivity	10^7	Z	Mohm	A	ASTM D257
Tensile Modulus	828 (120)	X,Y	MPa (kpsi)		
Ultimate Stress	6.9 (1.0)	X,Y	MPa (kpsi)	23ºC	ASTM D638
Ultimate Strain	7.3	X,Y	%		
Compressive Modulus	2482 (360)	Z	MPa (kpsi)		ASTM D638
Moisture Absorption	0.02	-	%	D48/50	IPC-TM-650, 2.6.2.1 ASTM D570
Thermal Conductivity	0.60	-	W/m/K	80ºC	ASTM C518
Coefficient of Thermal Expansion	16 16 24	X Y Z	ppm/ºC	(10K/min) TMA	ASTM D3386 IPC-TM-650 2.4.41
Td	500		ºC TGA		ASTM D3850
Density	2.1		gm/cm3		ASTM D792
Specific Heat	0.93 (0.22)	-	J/g/K (BTU/lb/ºF)	-	Calculated
Copper Peel	8.9 (1.6)		lbs/in (N/mm)		IPC-TM-650 2.4.8
Flammability	V-0				UL94
Lead-Free Process Compatible	YES				

6.2 Rectangular Patch

The objective of this chapter is to show you how to create, simulate and analyze a microstrip patch antenna resonating at a frequency of 7.5 GHz as shown in Fig.6.2
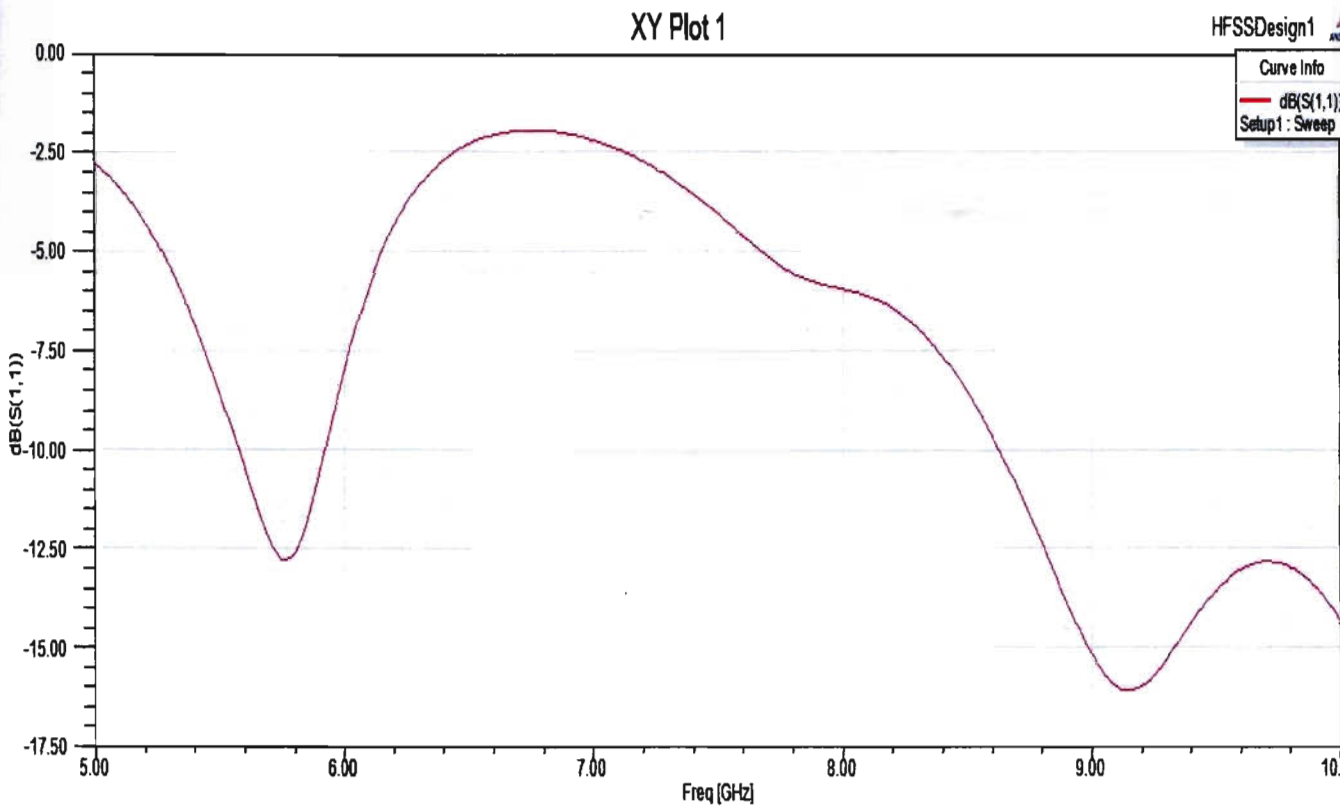

Fig 6.2: Rectangular Patch Antenna.

For this rectangular patch analysis the value of dielectric constant(ε_r) is 2.94, substrate material is Rogers RT/duroid 6002 ™. The properties of Rogers RT/duroid 6002 ™ is given in Table 6.1. The coordinate of the feed is (12.9,0,0) and the substrate thickness is 3.5 mm.

6.3 Simulated Results of Rectangular Patch Antenna

6.3.1 Return Loss
The simulated return loss of the optimized antenna from HFSS is shown in Fig.6.3. At 7.5 GHz a return loss of -10 dB is achieved.

Fig 6.3: Return Loss of Rectangular Patch Antenna in HFSS.

The percentage bandwidth of the antenna is calculated using the formula described in chapter 4.

% of BW= $(f_2 - f_1)/f_0 *100\% = 5.53\%$ where $f_0 = 5.78$, $f_1 = 5.59$ and $f_2 = 5.91$. The percentage bandwidth calculated using the above formula is tabulated in Table 6.2 and Table 6.3 for different substrate thickness and feed position respectively.

The dependence of percentage bandwidth on substrate thickness is shown in Fig 6.4 . It is found that at a thickness of 3.5 mm the maximum percentage bandwidth (5.53%) occurs.

Table6.2: Data Sheet of Different thickness of Rogers RT/duroid 6002™ for % of BW:

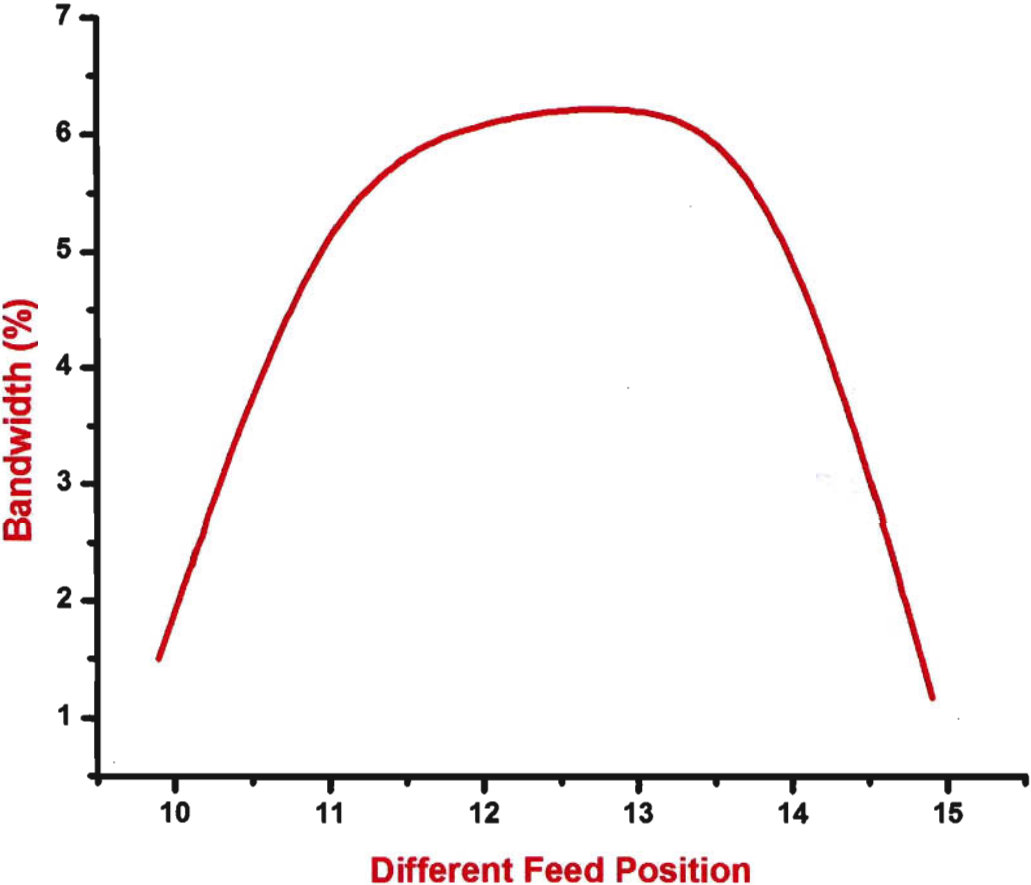| Material Name	Substrate Thickness (mm)	f_0	f_1	f_2	% of BW= $(f_2 - f_1)/f_0 *100\%$
Rogers RT/duroid 6002(tm)	0.45	5.88	5.85	5.91	1.02%
Rogers RT/duroid 6002(tm)	0.58	5.90	5.85	5.94	1.52%
Rogers RT/duroid 6002(tm)	0.66	5.90	5.83	5.93	1.69%
Rogers RT/duroid 6002(tm)	0.794	5.91	5.84	6.00	2.70%
Rogers RT/duroid 6002(tm)	0.89	5.82	5.72	5.91	3.26%
Rogers RT/duroid 6002(tm)	0.99	5.81	5.71	5.90	3.27%
Rogers RT/duroid 6002(tm)	1.5	5.78	5.62	5.90	4.84%
Rogers RT/duroid 6002(tm)	3.5	5.78	5.59	5.91	5.55%

Graph of Table 6.2
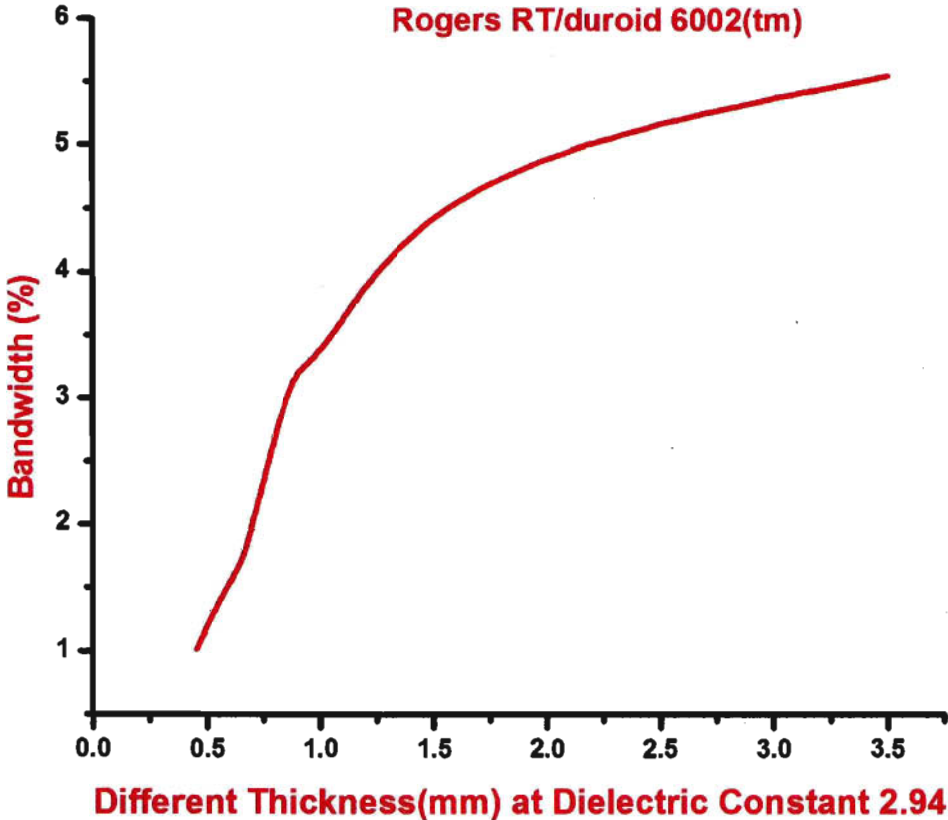
Fig 6.4:The dependence of percentage bandwidth on substrate thickness.

Table 6.3: Data Sheet of Different Feed position for % of BW:

| Material Name	Feed Position	f_0	f_1	f_2	% of BW= $(f_2 - f_1)/f_0 * 100\%$
PEC	9.9,0,0	5.85	5.81	5.90	1.5%
PEC	10.94,0,0	5.78	5.59	5.91	5.53%
PEC	11.9,0,0	5.72	5.54	5.89	6.12%
PEC	12.9,0,0	5.70	5.52	5.88	6.31%
PEC	13.9,0,0	5.71	5.55	5.89	5.95%
PEC	14.9,0,0	5.84	5.79	5.86	1.19%

Graph of Table 6.3

Fig 6.5: The dependence of percentage bandwidth on different feed position.

Table 6.4: Dielectric Constant of different Materials substrate thickness at 0.794 mm:

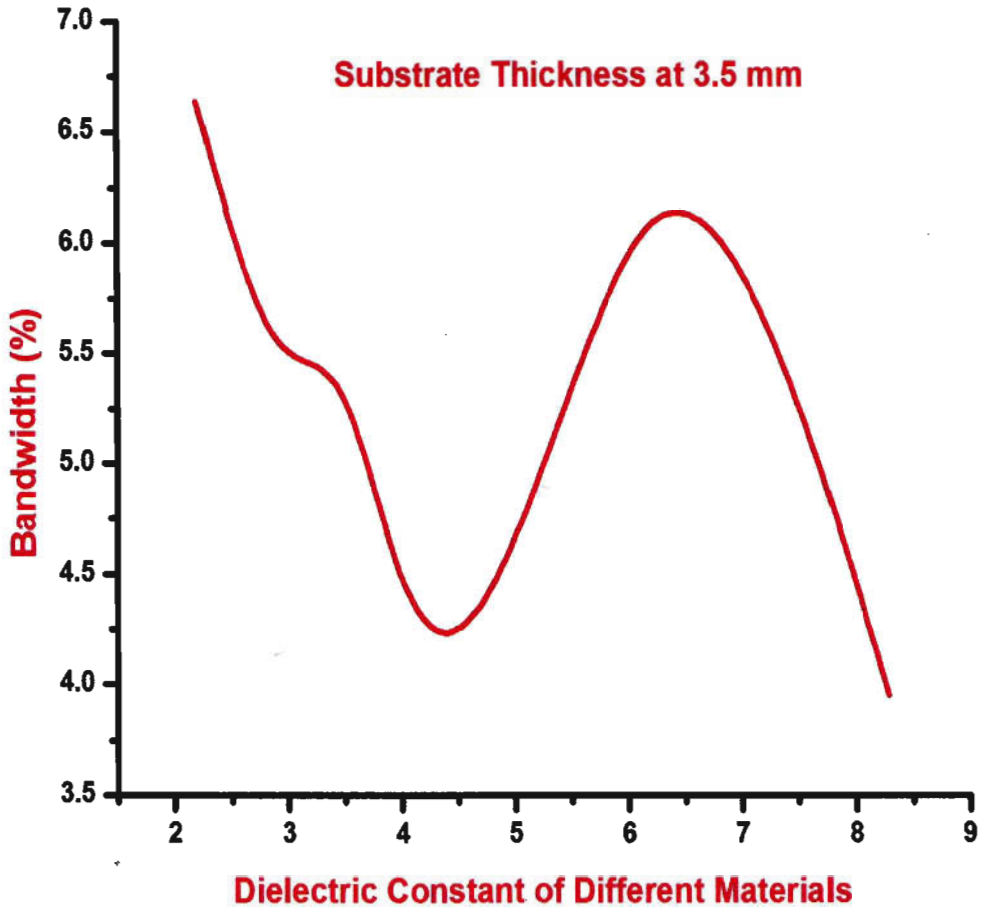| Material Name	Dielectric Constant	f_0	f_1	f_2	% of BW= $(f_2 - f_1)/f_0$ *100%
Rogers RT/duroid 5880(tm)	2.2	6.89	6.84	6.92	1.16%
Rogers RT/duroid 6002(tm)	2.94	5.91	5.84	6.00	2.7%
Neltech NH9350™	3.5	5.5	5.45	5.58	2.36%
Silicon-Dioxide	4	5.19	5.16	5.22	1.15%
Rogers RT/duroid 6006(tm)	6.15	6.23	6.21	6.26	0.80%
Marble	8.3	5.4	5.39	5.42	0.55%

Graph 0f Table 6.4
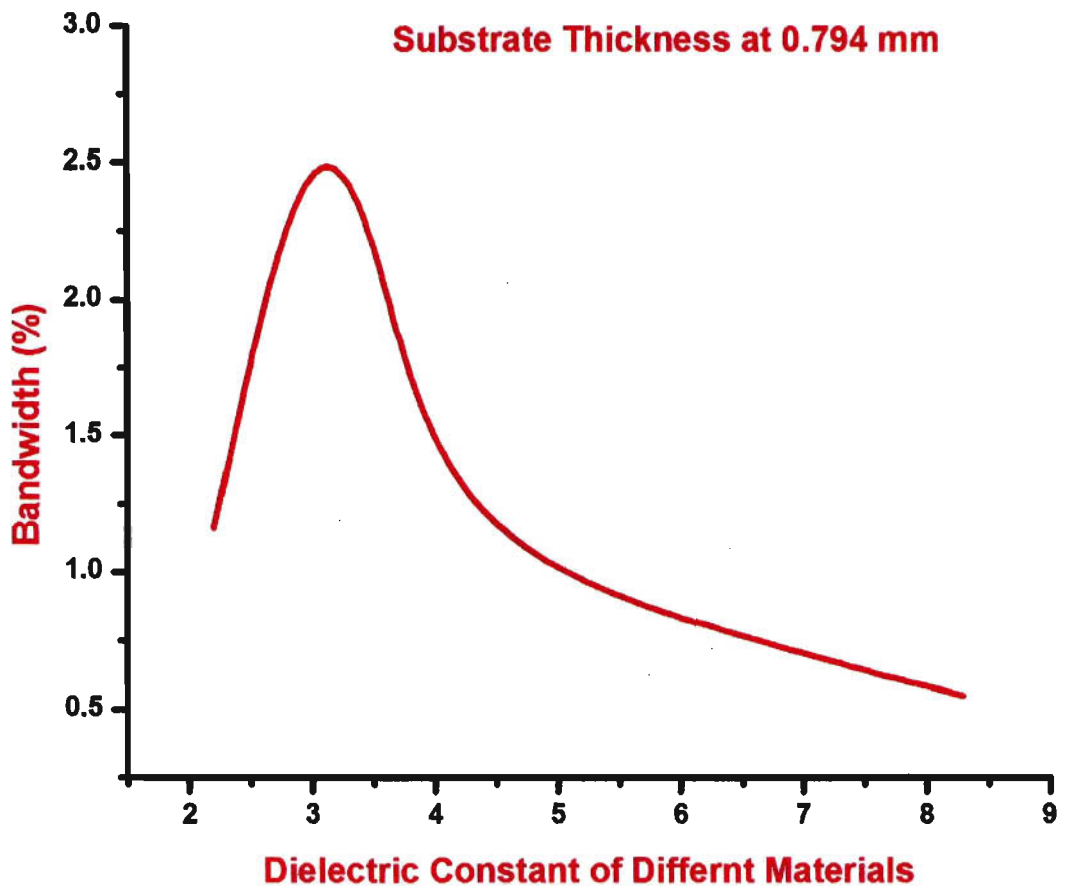
Fig 6.6: Dielectric Constant of different Materials thickness at 0.794 mm.

Table 6.5: Dielectric Constant of different Materials substrate thickness at 3.5 mm:

| Material Name	Dielectric Constant	f_0	f_1	f_2	% of BW= $(f_2 - f_1)/f_0$ *100%
Rogers RT/duroid 5880(tm)	2.2	6.32	6.10	6.52	6.64%
Rogers RT/duroid 6002(tm)	2.94	5.78	5.59	5.91	5.55%
Neltech NH9350™	3.5	5.39	5.22	5.51	5.30%
Silicon-Dioxide	4	5.10	5.00	5.23	4.50%
Rogers RT/duroid 6006(tm)	6.15	6.60	6.40	6.80	6.06%
Marble	8.3	5.80	5.67	5.90	3.96%

Graph 0f Table 6.5

Fig 6.7: Dielectric Constant of different Materials thickness at 3.5mm.

Table 6.6: Data Sheet of Different thickness of Rogers RT/duroid 5880™ for % of BW:

Material Name	Substrate Thickness (mm)	f_0	f_1	f_2	% of BW= $(f_2 - f_1)/f_0$ *100%
Rogers RT/duroid5880(tm)	0.794	6.68	6.59	6.78	2.84%
Rogers RT/duroid 5880(tm)	0.99	6.60	6.46	6.71	3.78%
Rogers RT/duroid 5880(tm)	1.5	6.50	6.32	6.62	4.61%
Rogers RT/duroid5880(tm)	2.5	6.41	6.20	6.61	6.39%
Rogers RT/duroid5880(tm)	3.5	6.32	6.10	6.52	6.64%
Rogers RT/duroid 5880(tm)	4	6.30	6.10	6.49	6.19%
Rogers RT/duroid5880(tm)	4.5	6.26	6.10	6.42	5.11%
Rogers RT/duroid 5800(tm)	5.5	6.10	6.00	6.21	3.44%

Graph 0f Table 6.6
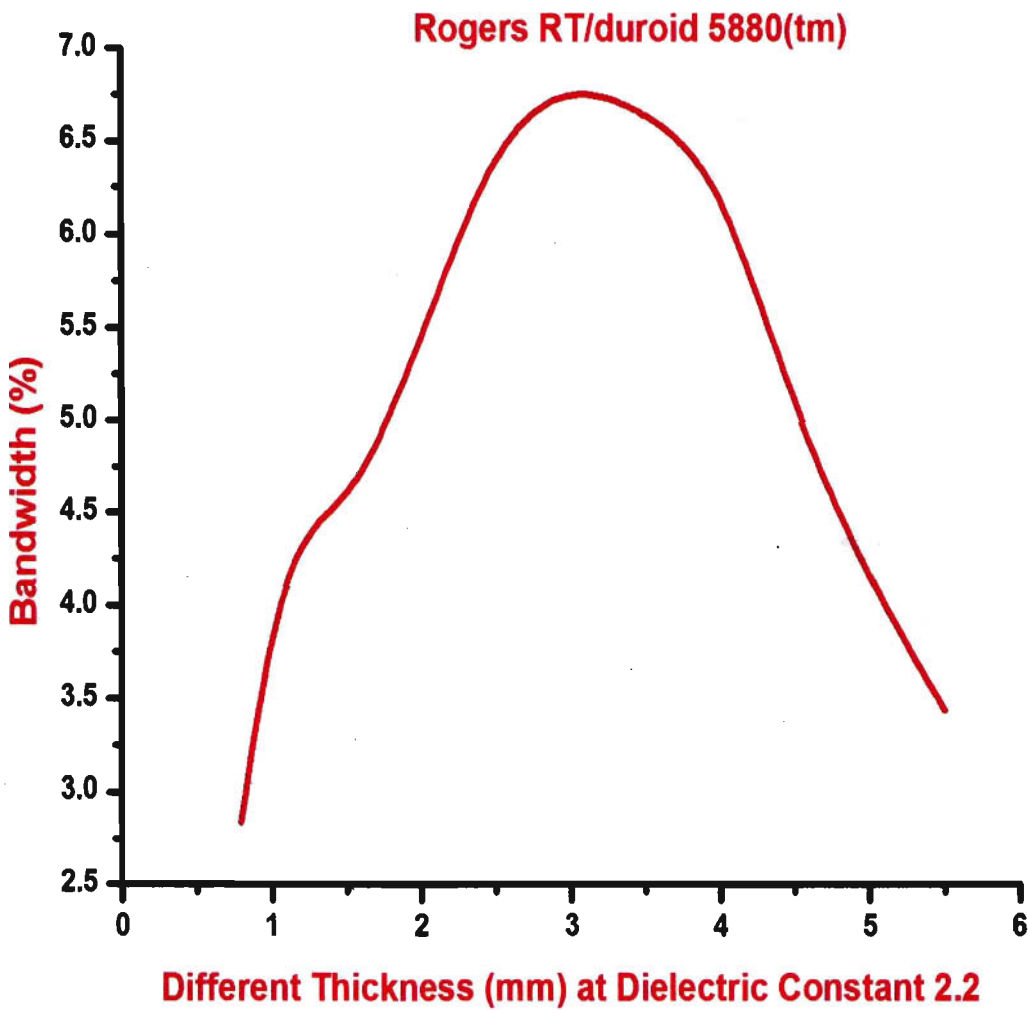
Fig 6.8: The dependence of percentage bandwidth on substrate thickness.
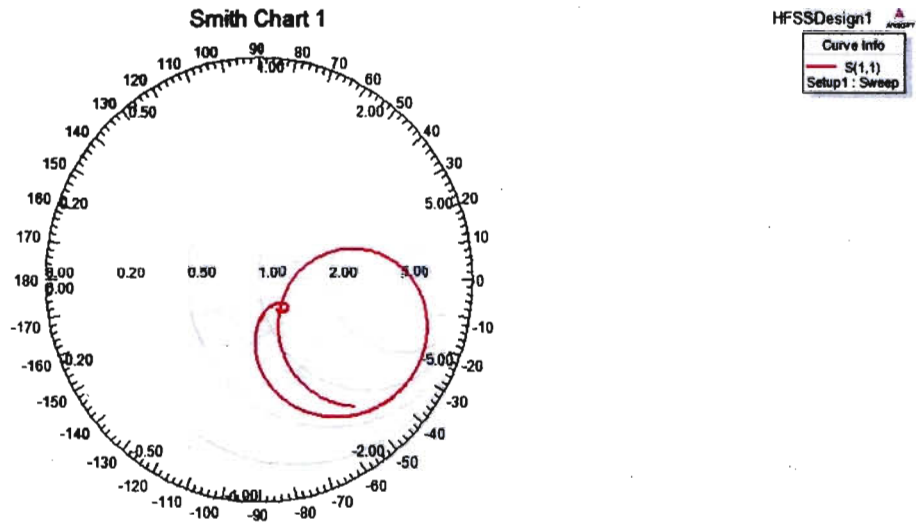
6.3.2 Input Impedance

Fig 6.9: Input Impedance from HFSS.

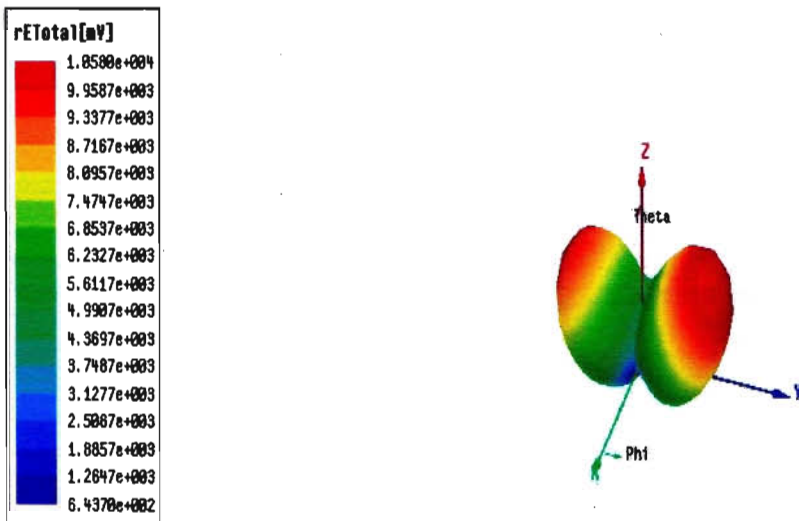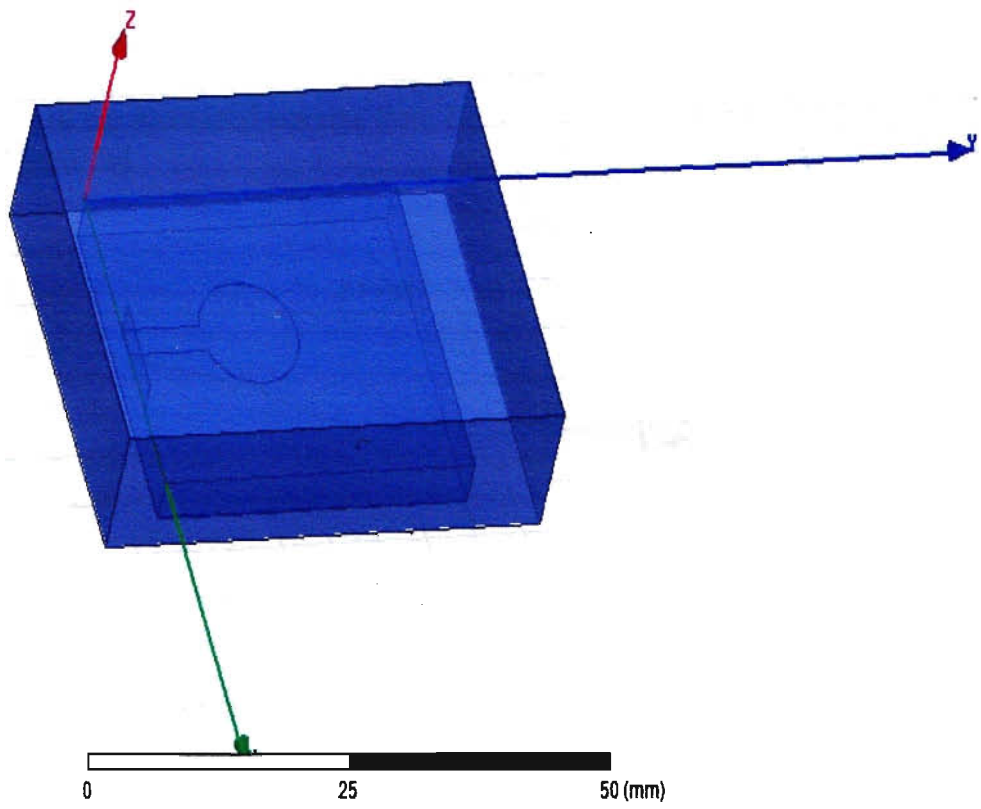## 6.3.3 Radiation Pattern

Fig 6.10:3D polar plot from HFSS.

6.4 Circular Patch Antenna

The objective of this chapter is to show you how to create, simulate and analyze a microstrip patch antenna resonating at a frequency of 7.5 GHz as shown in Fig 6.8
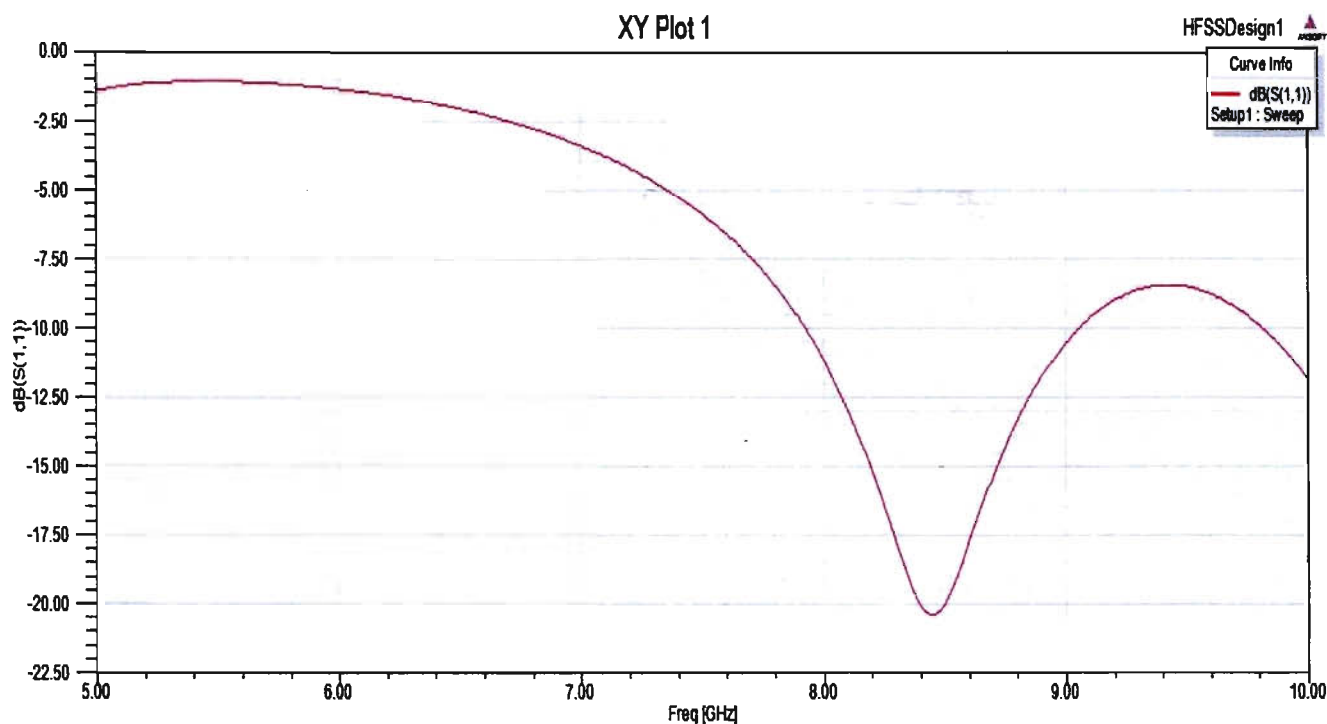

Fig 6.11: Circular Patch Antenna.

For this circular patch analysis the value of dielectric constant(ε_r) is 2.94, substrate material is Rogers RT/duroid 6002 ™. The properties of Rogers RT/duroid 6002 ™ is given in Table 6.1. The coordinate of the feed is (12.9,0,0), radius is 5 mm, height 0.05 and the substrate thickness is 3.5 mm.

6.5 Simulated Result of Circular Patch Antenna

6.5.1 Return Loss

The simulated return loss of the optimized antenna from HFSS is shown in figure. At 7.5 GHz a return loss of -10 dB is achieved.

Fig 6.12: Return Loss of Circular Patch Antenna in HFSS.

The percentage bandwidth of the antenna is calculated using the formula described in chapter 4.

% of BW= $(f_2 - f_1)/f_0$ *100% = 14.5% where $f_0 = 8.43$, $f_1 = 7.92$ and $f_2 = 9.13$. The percentage bandwidth calculated using the above formula is tabulated in Table 6.4 for different substrate thickness.

The dependence of percentage bandwidth on substrate thickness is shown in Fig.6.10. It is found that at a thickness of 3.5 mm the maximum percentage bandwidth (14.35%) occurs.

Table 6.7: Data Sheet of Different thickness of Rogers RT/duroid 6002™ for % of BW

| Material Name	Substrate Thickness (mm)	f_0	f_1	f_2	% of BW= $(f_2 - f_1)/f_0$ *100%
Rogers RT/duroid 6002(tm)	1.30	9.10	8.99	9.21	2.41%
Rogers RT/duroid 6002(tm)	1.50	9.03	8.68	9.35	7.41%
Rogers RT/duroid 6002(tm)	2.50	8.70	8.18	9.29	12.75%
Rogers RT/duroid 6002(tm)	3.50	8.43	7.92	9.13	14.35%
Rogers RT/duroid 6002(tm)	3.70	8.39	7.89	9.00	13.23%
Rogers RT/duroid 6002(tm)	3.90	8.37	7.88	8.93	12.54%
Rogers RT/duroid 6002(tm)	5.00	8.20	7.80	8.60	9.76%
Rogers RT/duroid 6002(tm)	5.50	8.15	7.90	8.39	6.01%

Graph of Table 6.7
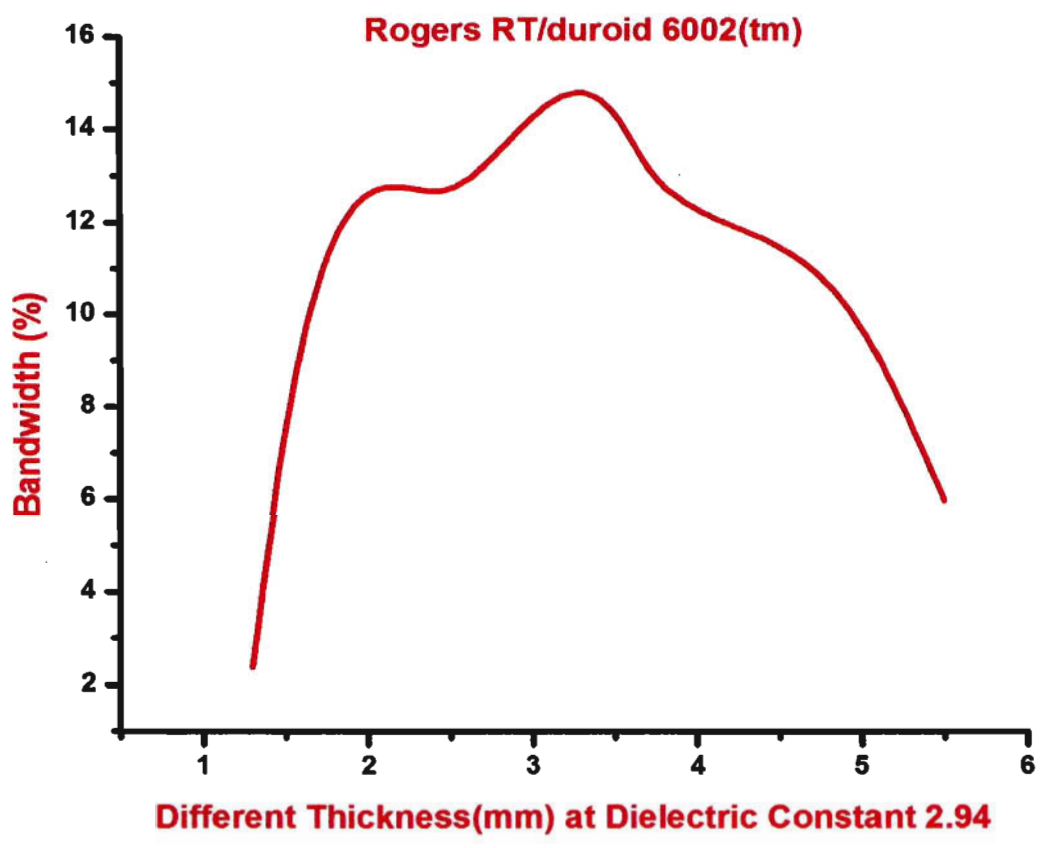
Fig 6.13: The dependence of percentage bandwidth on substrate thickness.

Table 6.8: Dielectric Constant of different Materials substrate thickness at 3.5 mm:

Material Name	Dielectric Constant	f_0	f_1	f_2	% of BW= $(f_2 - f_1)/f_0$ *100%
Rogers RT/duroid 5880(tm)	2.2	9.41	8.76	10	13.19%
Rogers RT/duroid 6002(tm)	2.94	8.43	7.92	9.13	14.35%
Neltech NH9350™	3.5	7.90	7.48	8.39	11.51%
Silicon-Dioxide	4	7.50	7.10	7.90	10.67%
Rogers RT/duroid 6006(tm)	6.15	6.24	6.00	6.50	8.01%
Marble	8.3	5.52	5.37	5.68	5.61%

Graph of Table 6.8
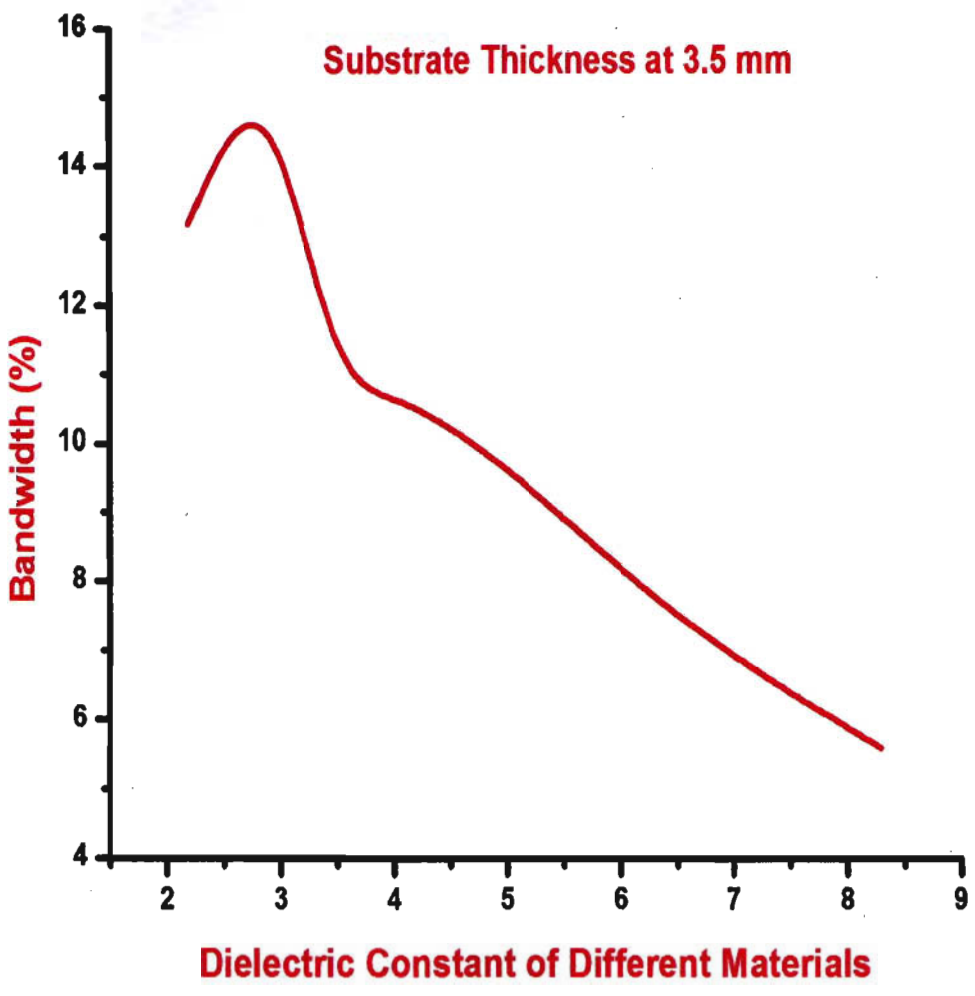
Fig 6.14:Dielectric Constant of different Materials thickness at 3.5 mm.
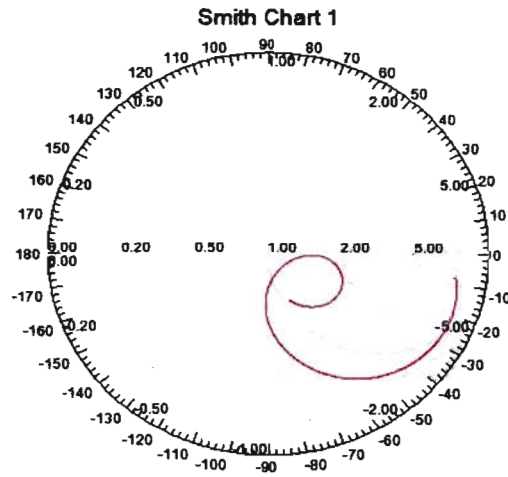
6.5.2 Input Impedance

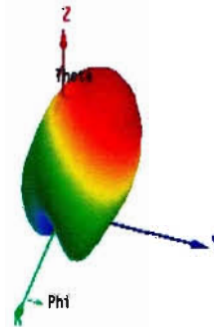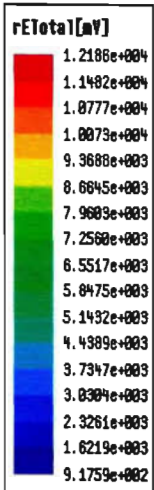**Fig 6.15:**Input Impedance from HFSS.

6.5.3 Radiation Pattern

Fig 6.16:3D polar plot from HFSS.

Chapter 7

Conclusion

In this paper we **design** rectangular patch antenna and circular patch antenna for different materials at **different thickness** (mm) using different substrate material (having different ε_r) and feed position by using High Frequency Structure Simulator (HFSS) software. The overall working of antennas was understood. The major parameters (such as Return Loss, Radiation Patterns, Directivity and Bandwidth) that affect design and applications were studied and their implications understood. In this project using various types of materials for substrate thickness for better bandwidth (%). For changing substrate thickness every materials have their best bandwidth (%) at a certain thickness. For rectangular patch, we used Rogers RT/duroid 6002™ (dielectric constant, ε_r is 2.94) as substrate material. For a thickness of 3.5 mm the maximum percentage bandwidth is 5.55%. For the same patch using Rogers RT/duroid 5880 ™ (dielectric constant ε_r is 2.2) with thickness of 3.5 mm the maximum percentage bandwidth is 6.64%. For the circular patch antenna we used Rogers RT/duroid 6002™ with thickness of 3.5 mm and dielectric constant (ε_r) is 2.94. We found that the percentage bandwidth of this circular patch is 14.35%.

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