IMPLEMENTATION OF CROSS-SHAPED SLOT IN COMPACT MICROSTRIP ANTENNA

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CERTIFICATE

This is to certify that the work contained in this dissertation entitled, **"IMPLEMENTATION OF CROSS-SHAPED SLOT IN COMPACT MICROSTRIP ANTENNA"** submitted by RAVINDER KUMAR (Roll No: 13822) of Delhi College of Engineering in partial fulfillment of the requirements for the award of Master of Engineering Degree in **ELECTRONICS AND COMMUNICATION ENGINEERING** at Delhi College Of Engineering (University Of Delhi) is an authentic work carried out by him under my supervision and guidance. To the best of my/our knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree.

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TABLE OF CONTENTS

List of Figure and Table

5.5.4 Material- Roger 4350 ; Electrical Permittivity (ε*r*) : 3.48

5.5.5 Material- Epoxy ; Electrical Permittivity (ε*r*) : 3.6

5.5.6 Material- FR4 ; Electrical Permittivity (ε*r*) : 4.4

5.5.7 Material- Glass ; Electrical Permittivity (ε*r*) : 5.5

5.5.8 Material- Duroid 6010; Electrical Permittivity (ε*r*) : 10.2

Chapter 6

Elevation Pattern

Azimuth Pattern

List of Table

ABSTRACT

A compact cross-shaped slotted microstrip patch antenna is proposed for circularly polarized (CP) radiation. A symmetric, cross-shaped slot is embedded along one of the diagonal axes of the circular patch for CP radiation and antenna size reduction. The structure is asymmetric (unbalanced) along the diagonal axes. The overall size of the antenna with CP radiation can be reduced by cross shaped slot. The symmetric cross-shaped slot cut within the first quadrant of the circular patch. There are huge demands for the miniaturization of the mobile communications equipment. Microstrip circularly polarized antennas are attractive in satellite communication systems owing to their good features such as low profile, light weight and easy to fabricate. A number of single-fed circularly polarized microstrip antennas are described. The major advantage of single-feed circularly polarized microstrip is their simple structure. There are a number of approaches to reduce the size of patch antennas . embedding cross slots of unequal length or equal lengths .

In this thesis the performance of the cross-shaped microstrip antenna is studied with various types of substrate which have different types of electrical permittivity with same thickness is about 1.6mm. Now a days the Selection of the most suitable substrate for a Microstrip antenna is a prime important. There is because of many limitations of the microstrip antenna such as high return loss, low gain and low efficiency can be overcome by selecting an appropriate substrate for fabrication of the antenna. The substate properties such as its dielectric constant, loss tangent have a pronounced effect on the antenna characteristics. The radius of circular patch is 24.8mm. The antenna is operated at 2.091 GHz, and built by using a Benzo-cyclo-buten material which gives good antenna parameters. The Electrical permittivity of this substrate is 2.6. with a coaxial probe single feed. All analytical results have been simulated by IE3D software.

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Symbols & Abbreviations

εr	Relative permittivity of the substrate
ϵeff	effective Dielectric constant of subtract
Ω	Ohm resistance
VSWR	Voltage standing wave ratio
BW	Bandwidth
Q	Quality factor
S11	Input reflection coefficient
dB[S(1,1)]	Return loss in dB
G	Gain of antenna
Z(1,1)	Input impedance of two port network
Λ	Wavelength of EM wave
C	Velocity of light in air
fo	Center frequency
Zo	Characteristics Impedance
λ	Wavelength
h	Height of substrate
t	Thickness of Patch
L	Length of the Patch
tan δ	Loss tangent of substrate

CHAPTER-1

INTRODUCTION

1.1 General overview

Communication between humans was first by sound through voice. With the desire for slightly more distance communication came, devices such as drums, then visual methods such as signal flags and smoke signals were used. These optical communication devices, of course, utilized the light portion of the electromagnetic spectrum. It has been only very recent in human history that the electromagnetic spectrum, outside the visible region, has been employed for communication, through the use of radio. One of humankind’s greatest natural resources is the electromagnetic spectrum and the antenna has been instrumental in harnessing this resource. Satellite communication and Wireless communication has been developed rapidly in the past decades and it has already a dramatic impact on human life. In the last few years, the development of wireless local area networks (WLAN) represented one of the principal interests in the information and communication field. Thus, the current trend in commercial and government communication systems has been to develop low cost, minimal weight, low profile antennas that are capable of maintaining high performance over a large spectrum of frequencies. This technological trend has focused much effort into the design of Microstrip (patch) antennas.

With a simple geometry, patch antennas offer many advantages not commonly exhibited in other antenna configurations. For example, they are extremely low profile, lightweight, simple and inexpensive to fabricate using modern day printed circuit board technology, compatible with microwave and millimeter-wave integrated circuits (MMIC), and have the ability to conform to planar and non planar surfaces. In addition, once the shape and operating mode of the patch are selected, designs become very versatile in terms of operating frequency, polarization, pattern, and impedance. The variety in design that is possible with Microstrip antenna probably exceeds that of any other type of antenna element. In this thesis Cross-Shaped Compact Microstrip antenna is designed simulated and tested. There are a few software available which allow the optimization of the antenna. IE3D one of the most imperial electromagnetic software which allows to solving for radio and microwave application. It works based on method of movement (MOM) .The simulator tool computes most of the useful quantities of interest such as radiation pattern, input impedance and gain etc.

1.2 Dissertation Motivation

With bandwidths as low as a few percent, broadband applications using conventional Microstrip patch designs are limited. Other drawbacks of patch antennas include low efficiency, limited power capacity, spurious feed radiation, poor polarization purity, narrow bandwidth, and manufacturing tolerance problems. For over two decades, research scientists have developed several methods to increase the bandwidth and low frequency ratio of a patch antenna. Many of these techniques involve adjusting the placement and/or type of element used to feed (or excite) the antenna. Today's the size and the selection of substrate of microstrip antenna is also a very typical job. For reducing the size of antenna a compact technique Compact circularly polarized microstrip antennas (CPMAs) are useful for handheld, portable devices, medical implant communication service (MICS), and compact mobile communication systems. Circular polarization is one of the most common polarization types used in current wireless communication systems, as it is independent of the transmitting and receiving antenna orientations. Many applications need compact CPMAs, where the overall antenna size is a major consideration, such as receiver antennas for medical implanted applications , mobile wireless, radio frequency identification (RFID) readers and portable wireless devices. For handheld and portable wireless systems, antenna size is very important, especially for low frequency bands, with respect to the antenna gain and bandwidth.

1.3 Literature Review and Methodology

The invention of Microstrip patch antennas has been attributed to several authors, but it was certainly dates in the 1960s with the first works published by Deschamps, Greig and Engleman, and Lewin, among others. After the 1970"s research publications started to flow with the appearance of the first design equations. Since then different authors started investigations on Microstrip patch antennas like James Hall and David M. Pozar and there are also some who contributed a lot. Throughout the years, authors have dedicated their investigations to creating new designs or variations to the original antenna that, to some extent; produce either wider bandwidths or multiple-frequency operation in a single element. However, most of these innovations bear disadvantages related to the size, height or overall volume of the single element and the improvement in bandwidth suffers usually from a degradation of the other characteristics. It is the purpose of this thesis to introduce the general techniques produced to improve the narrow bandwidth and low frequency ratio of patch antennas.

1.4 Dissertation Outline

The outline of this thesis is as follows.

Chapter 2: The thesis begins with the basic theory of MSAs, including the basic geometries , feeding method and characteristics of the MSA, different types of slot, the advantages and disadvantages of MSAs, types of waves impedance matching, shorting techniques, the methods of analysis used for the MSA design.

Chapter 3: In this chapter the basics of antenna parameters such as return loss, polarization,radiation pattern, impedance, VSWR, gain ,directivity , etc. are presented.

Chapter 4: This chapter describes the design specification of Microstrip patch antenna with different types of substrates and simulation result using the IE3D electromagnetic simulation software. The theoretical and simulation results are presented.

Chapter 5: In this chapter describes the Cross-shaped slot in compact Microstrip antenna and finally comparison between the simulation and theoretical results using IE3D.

Chapter 6: This chapter contains conclusion and scope of future work.

CHAPTER-2

MICROSTRIP ANTENNA

2.1 Introduction

A microstrip antenna consists of conducting patch on a ground plane separated by dielectric substrate. This concept was undeveloped until the revolution in electronic circuit miniaturization and large-scale integration in 1970. After that many authors have described the radiation from the ground plane by a dielectric substrate for different configurations. The early work of Munson on micro strip antennas for use as a low profile flush mounted antennas on rockets and missiles showed that this was a practical concept for use in many antenna system problems. Various mathematical models were developed for this antenna and its applications were extended to many other fields. The number of papers, articles published in the journals for the last ten years, on these antennas shows the importance gained by them. The micro-strip antennas are the present day antenna designer's choice. Low dielectric constant substrates are generally preferred for maximum radiation. The conducting patch can take any shape but rectangular and circular configurations are the most commonly used configuration. Other configurations are complex to analyze and require heavy numerical computations. A microstrip antenna is characterized by its Length, Width, Input impedance, and Gain and radiation patterns. Various parameters of the microstrip antenna and its design considerations were discussed in the subsequent chapters. The length of the antenna is nearly half wavelength in the dielectric. It is a very critical parameter, which governs the resonant frequency of the antenna. There are no hard and fast rules to find the width of the patch. Microstrip patch antenna used to send on board parameters of article to the ground while under operating conditions. The aim of the project is to design and fabricate a cross shaped Microstrip Patch Antenna and study the effect of antenna dimensions Length (L), and substrate parameters, relative Dielectric constant (εr), substrate thickness (t) on the Radiation parameters of antenna.

One of the most exciting developments in antenna and electromagnetic history is the advent of Microstrip antenna (known also as patch antenna). It is probably the most versatile solution to many systems requiring planner radiating element. Microstrip antenna falls into the category of printed antennas: radiating elements that utilize printed circuit manufacturing processes to develop the feed and radiating structure.

Of all the printed antennas, including dipole, slots, and tapered slots; Microstrip antenna is by far the most popular and adaptable. This is because of all its salient features: including ease of fabrication, good radiation control, and low cost of production. The Microstrip antenna is constructed from dielectric substrate and patch metal and that a portion of the metallization layer is responsible for radiation. Through decades of research, it was identified that the performance and operation of a Microstrip antenna is driven mainly by the geometry of the printed patch and the material characteristics of the substrate onto which the antenna is printed.

2.2 Basic characteristics

Microstrip antennas consist of a pair of parallel conducting layers separating a dielectric medium, referred as substrate. In this configuration, the upper conducting layer or "patch" is the source of radiation where electromagnetic energy fringes off the edges of the patch and into the substrate. The lower conducting layer acts as a perfectly reflecting ground plane, bouncing energy back through the substrate and into free space. Physically, the patch is a thin conductor that is an appreciable fraction of a wavelength in extent. The patch which has resonant behavior is responsible to achieve adequate bandwidth. Conventional patch designs yield few percent bandwidths. In most practical applications, patch antenna is rectangular or circular in shape; however, in general, any geometry is possible.

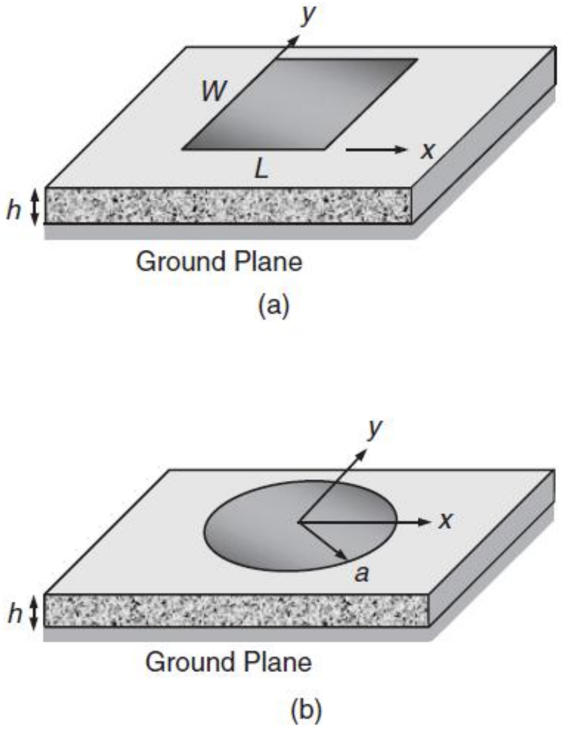


Fig 2.1 (a) Rectangular & (b) Circular Microstrip Patch Antenna

Microstrip antennas are among the most widely used types of antennas in the microwave frequency range, and they are often used in the millimeter-wave frequency range as well [1, 2, 3]. Below approximately 1 GHz, the size of a microstrip antenna is usually too large to be practical. Also called patch antennas, microstrip patch antennas consist of a metallic patch of metal that is on top of a grounded dielectric substrate of thickness *h*, with relative permittivity and permeability ε_r and μ_r as shown in Figure 2.1 (usually μ_r=1). The metallic patch may be of various shapes, with rectangular and circular being the most common, as shown in Figure 2.1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

The rectangular patch and the circular patch have same basic principles. (Many of the CAD formulas is presented which will apply approximately for the circular patch if the circular patch is modeled as a square patch of the same area) [7] [8]. Various methods may be used to feed the patch, as discussed below. The advantage of the microstrip antenna is that it is usually low profile, in the sense that the substrate is fairly thin. If the substrate is thin enough, the antenna actually becomes "conformal," meaning that the substrate can be bent to conform to a curved surface e.g a cylindrical structure. A typical substrate thickness is about 0.02 λ_0. The metallic patch is usually fabricated by a photolithographic etching process or a mechanical milling process, making the construction relatively easy and inexpensive (the cost is mainly that of the substrate material). Other advantages include the fact that the microstrip antenna is usually lightweight (for thin substrates) and durable.

2.3 Basic principles of operation

The metallic patch essentially creates a resonant cavity, where the patch is the top of the cavity, the ground plane is the bottom of the cavity, and the edges of the patch form the sides of the cavity. The edges of the patch act approximately as an open-circuit boundary condition. Hence, the patch acts approximately as a cavity with perfect electric conductor on the top and bottom surfaces, and a perfect "magnetic conductor" on the sides [5] [16]. This point of view is very useful in analyzing the patch antenna, as well as in understanding its behavior. Inside the patch cavity the electric field is essentially z *directed* and independent of the z coordinate. Hence, the patch cavity modes are described by a double index (*m*, *n*). For the (*m*, *n*) cavity mode of the rectangular patch the electric field has the form:

$$E_z(x,y) = A_{mn}\cos\left(\frac{m\pi x}{L}\right)\cos\left(\frac{n\pi y}{W}\right)$$

Where *L* is the patch length and *W* is the patch width. The usual mode of operation for a broadside pattern is the TM_{10} mode, which has no y variation and has a length L that is approximately one-half wavelength in the dielectric. The surface current on the bottom of the metal patch is then x directed, and is given by

$$J_{sx}(x) = A_{10}\left(\frac{\pi / L}{j\omega\mu_0\mu_r}\right)$$

For this mode the patch may be regarded as a wide microstrip line of width *W*, having a resonant length *L* that is approximately one-half wavelength in the dielectric. The current is maximum at the centre of the patch, *x* = *L*/2, while the electric field is maximum at the two "radiating" edges x=0 and x=L. The width *W* is usually chosen to be larger than the length (*W* =1.5 *L* is typical) to maximize the bandwidth, since the bandwidth is proportional to the width.

2.4 Different Shape of Microstrip patch Antenna

Conducting patch can take any shape but rectangular and circular configurations are the most commonly used configuration. Other configurations are complex to analyze and require heavy numerical computations. Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. 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. However, such a configuration leads to a larger antenna size. In order to design a compact Microstrip patch antenna, substrates with higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a trade-off must be realized between the antenna dimensions and antenna performance. Dual characteristics are exhibited by rectangular patch having square notch at its centre. Compactness of antenna is also achieved by having square notch at centre as it reduces the size of antenna by 17% of the conventional antenna without slot. But these types of antennas suffer from drawback of excitation of surface waves which leads to lower gain and antenna efficiency.

Introduction of a prohibiting the propagation of all the electromagnetic waves of certain band of frequencies. Electromagnetic Band Gap (EBG) structure in the ground plane reduces the excitation of surface waves. The EBG structure consists of a uniformly distributed periodic metallic pattern on one side of a dielectric slab which is capable of eliminating surface wave. Common shapes of microstrip patch is given below:

Common Shapes of microstrip patch elements

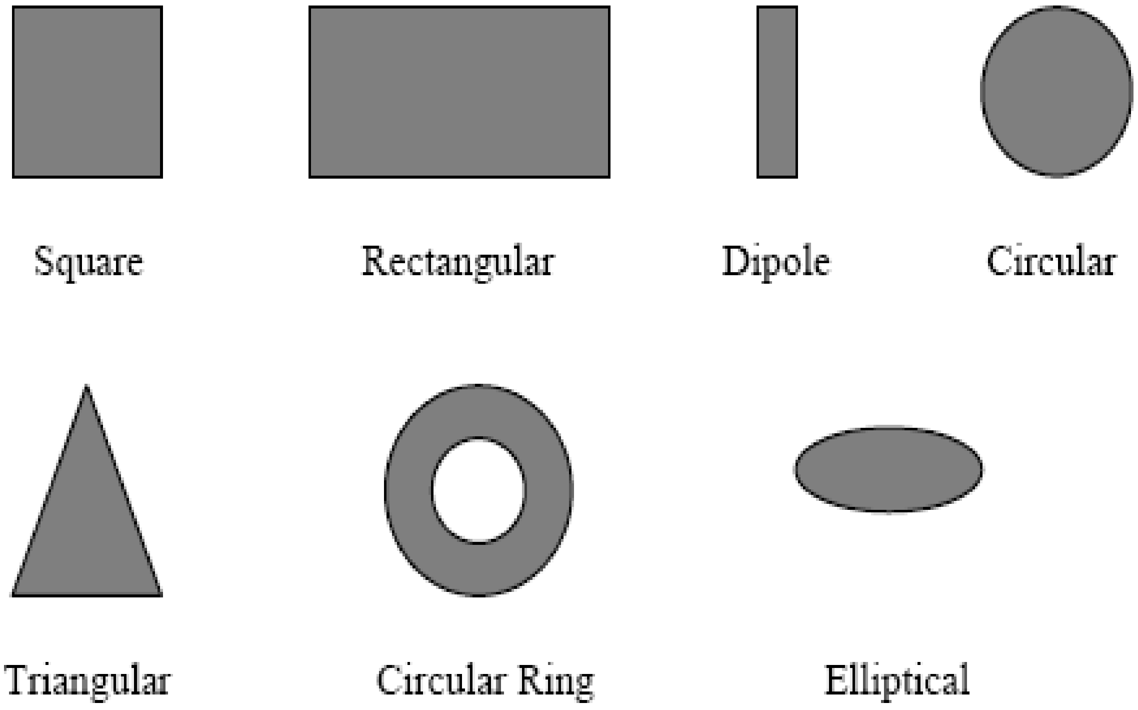


Fig2.2

2.5 Advantages and Disadvantages of Microstrip Antenna

Microstrip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Therefore they are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc. The telemetry and communication antennas on missiles need to be thin and conformal and are often in the form of Microstrip patch antennas. Another area where they have been used successfully is in Satellite Communication.

2.5.1 Advantages of Microstrip Antenna

- Light weight and low volume.
- Low profile planar configuration which can be easily made conformal to host surface.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization
- Can be easily integrated with microwave integrated circuits
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rigid surfaces.
- Can be easily integrated with microwave integrated circuits (MICs).

2.5.2 Disadvantages of Microstrip Antenna

- Low efficiency
- Low Gain
- Extraneous radiation from feeds and junctions
- Narrow bandwidth
- Poor end fire radiator except tapered slot antennas
- Low power handling capacity.
- Surface wave excitation
- very high antenna quality factor (Q).

Q can be reduced by increasing the thickness of the dielectric substrate. But as the thickness increases, an increasing fraction of the total power delivered by the source goes into a surface wave. This surface wave contribution can be counted as an unwanted.

2.6 Application of Microstrip Antenna

- Satellite communications
- Doppler and other radar
- Radio altimeters
- Missile telemetry
- Feed elements in complex antennas
- Satellite navigation receiver
- Biomedical radiator
- Command and control
- Wireless LANs
- Environmental instrumentation and remote sensing

2.7 Feed Techniques

Selection of feeding techniques is governed by a number of factors. The most important consideration is the efficient transfer of power between the radiating structure and feed structure, that is, impedance matching between the two. Associated with impedance matching are stepped impedance transformers, bends, stubs, junctions, and so on, which introduce discontinuities leading to spurious radiation and surface wave loss. The undesired radiation may increase the sidelobe level and cross-polar amplitude of the radiation pattern. Minimization of spurious radiation and its effect on the radiation pattern is one of the important factors for evaluation of the feed. Another consideration is the suitability of the feed for array applications. Some feed structures are amenable to better performance because of the larger number of parameters available.

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories- contacting and non-contacting. In the contacting method, the RF power is feed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).

2.7.1 Microstrip Line Feed

A conducting strip is connected directly to the edge of the Microstrip patch as shown in Figure 2.5. 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.

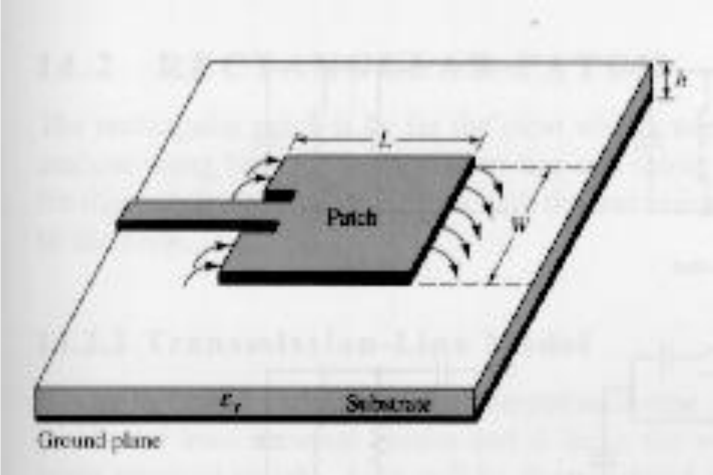


Fig 2.3 Rectangular Microstrip antenna Microstrip line feeding

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. This is an easy feeding method, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. Easy to match by controlling inset position. If the thickness of the dielectric substrate being used, increases then surface wave exiciation and spurious feed-line radiation also increases, which hampers the BW of the antenna. The spurious feed radiation also leads to undesired cross polarized radiation.

2.7.2 Coaxial Feed (Probe feed)

The Coaxial feed is also called probe feed. It is a very common technique used for feeding Microstrip antennas. As seen from Figure 2.6, 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.

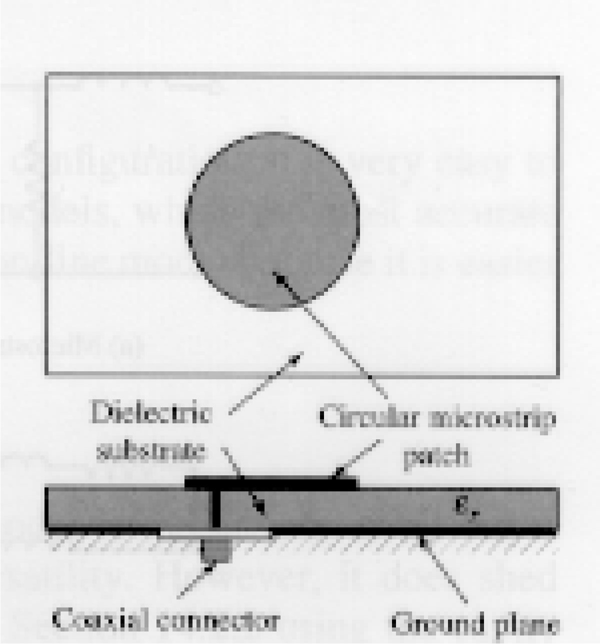


Fig. 2.4 Rectangular Microstrip antenna coaxial feed

The advantage of this feeding method 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. A major disadvantage of this feeding 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. Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems. It is seen above that for a thick dielectric substrate, which provides broad bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages. Matching is difficult with thicker substrate. The non-contacting feed techniques solve these types of problem.

2.7.3 Aperture Coupled Feed

In aperture coupled of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 2.7, 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.

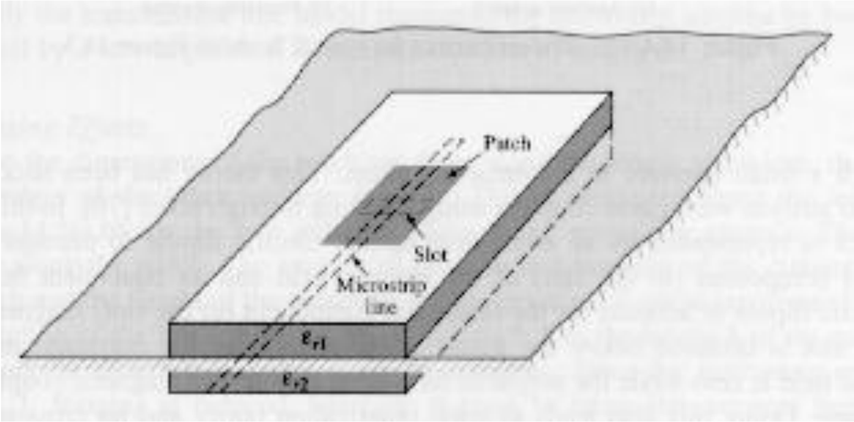


Fig. 2.5 Aperture-coupled feed

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. It allow independent optimization of feed substrate and gives More spurious radiation due to slots.

2.7.4 Proximity Coupled Feed (Electromagnetic coupling feed)

This type of feed technique is also called as the electromagnetic coupling feed. As shown in Figure 2.8, 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.

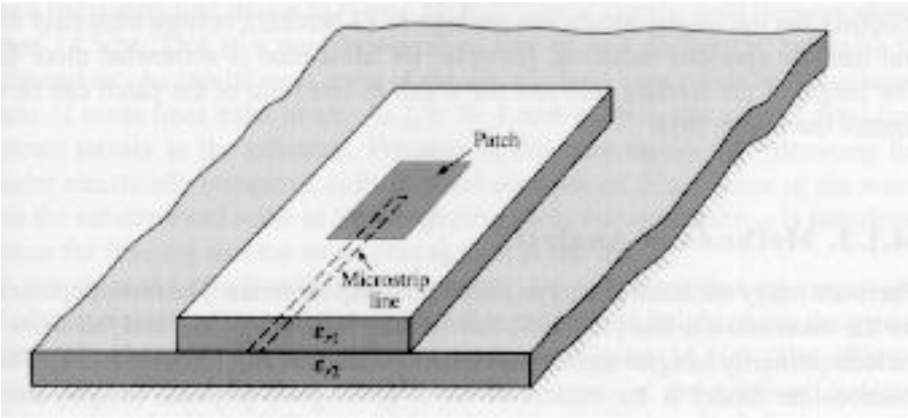


Fig.2.6 Proximity-coupled Feed

The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth, 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 main disadvantage of this types of feed is that it is very difficult to fabricate because of the two dielectric layers which need proper alignment. By using two dielectric layers overall thickness of the antenna is increased.

2.8 Equivalent circuits of typical feeding methods

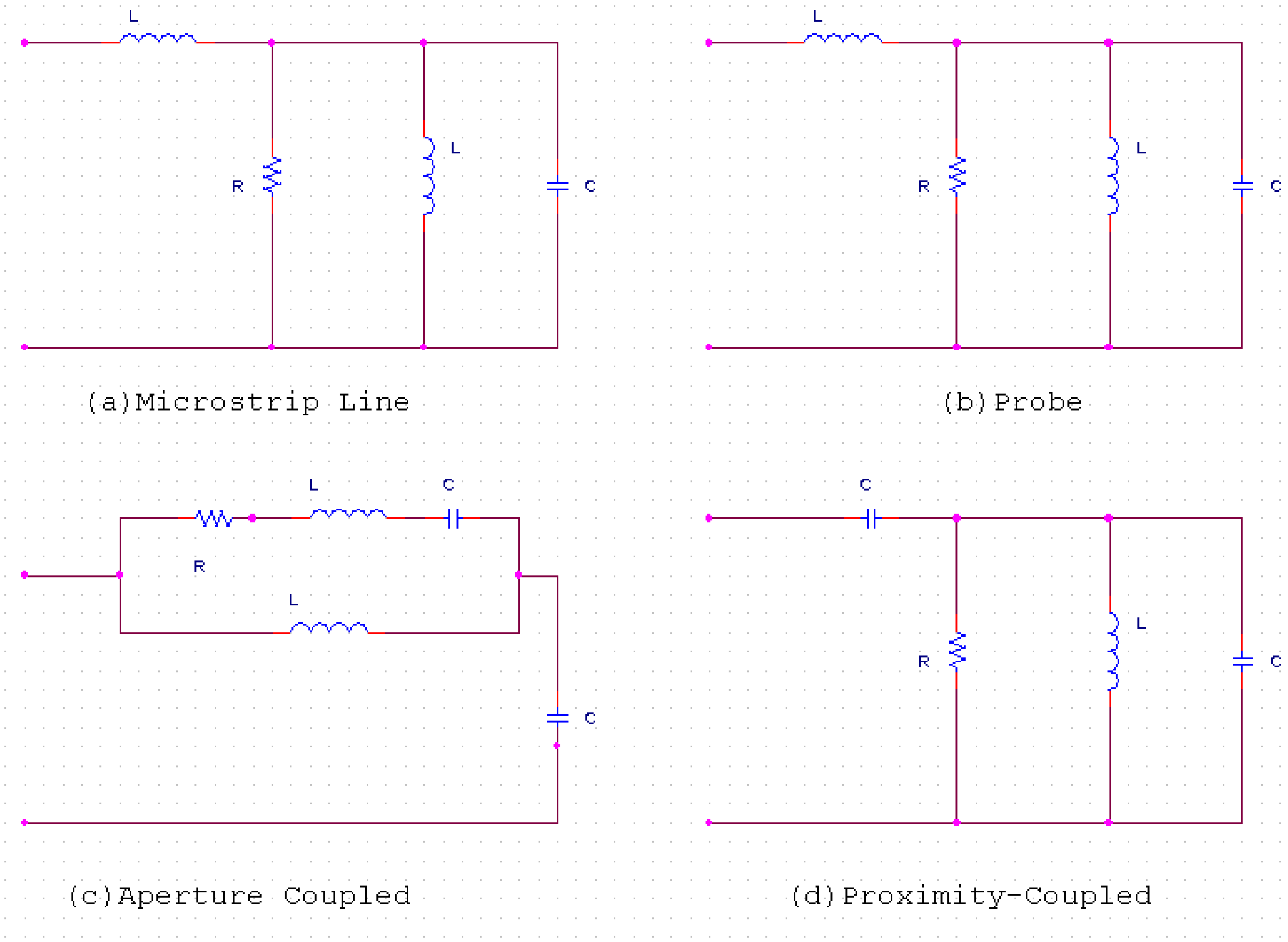


Fig. 2.7

CHAPTER-3

METHOD OF ANALYSIS

3.1 Waves on Microstrip Antenna

The mechanisms of transmission and radiation in a microstrip can be understood by considering a point current source (Hertz dipole) located on top of the grounded dielectric substrate (fig.3.1) This source radiates electromagnetic waves. Depending on the direction toward which waves are transmitted, they fall within three distinct categories, each of which exhibits different behaviors.

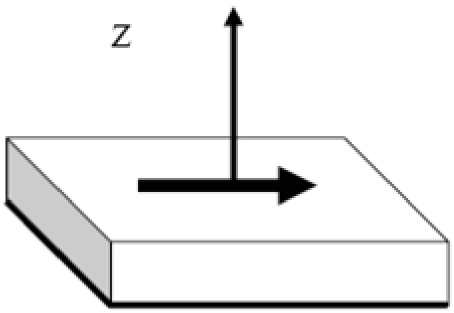


Fig.3.1 Hertz dipole on Microstrip Substrate

3.1.1 Surface Waves

In microstrip antenna in addition to radiation,surface waves may be exicited giving rise to entire radiation.These waves are TM and TE modes which propagates into the substrate outside the microstrip patch. The phase velocity of the surface waves is strongly dependent on the dielectric constant (εr) and thickness (h) of the substrate. The waves transmitted slightly downward, having elevation angles θ between $\pi/2$ and π - arcsin ($1/\sqrt{\varepsilon r}$), meet the ground plane, which reflects them, and then meet the dielectric-to-air boundary, which also reflects them (total reflection condition). The magnitude of the field amplitudes builds up for some particular incidence angles that leads to the excitation of a discrete set of surface wave modes; which are similar to the modes in metallic waveguide.

The fields remain mostly trapped within the dielectric, decaying exponentially above the interface (fig.2.11). The vector α, pointing upward, indicates the direction of largest attenuation. The wave propagates horizontally along β, with little absorption in good quality dielectric. With two directions of α and β orthogonal to each other, the wave is a non-uniform plane wave. Surface waves spread out in cylindrical fashion around the excitation point, with field amplitudes decreasing with distance (r), say$1/r$, more slowly than space waves.

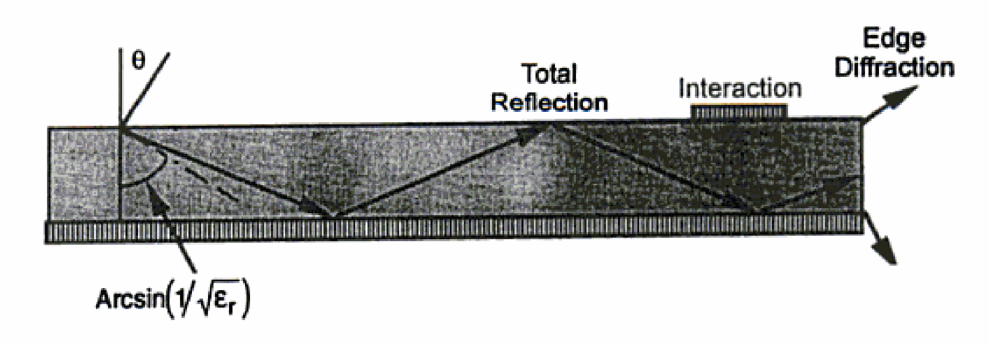


Fig.3.2 Surface Wave

The same guiding mechanism provides propagation within optical fibers. Surface waves take up some part of the signal's energy, which does not reach the intended user. The signal's amplitude is thus reduced, contributing to an apparent attenuation or a decrease in antenna efficiency. Additionally,the surface waves also introduce spurious coupling between different circuit or antenna elements.

This effect severely degrades the performance of microstrip filters because the parasitic interaction reduces the isolation in the stop bands.In large periodic phased arrays, the effect of surface wave coupling becomes particularly obnoxious, and the array can neither transmit nor receive when it is pointed at some particular directions (blind spots).

This is due to a resonance phenomenon, when the surface waves excite in synchronism the Floquet modes of the periodic structure. Surface waves reaching the outer boundaries of an open microstrip structure are reflected and diffracted by the edges. The diffracted waves provide an additional contribution to radiation, degrading the antenna pattern by raising the side lobe and the cross polarization levels. Surface wave effects are mostly negative, for circuits and for antennas, so their excitation should be suppressed if possible.

3.1.2 Leaky Waves

Waves directed more sharply downward, with θ angles between π - arcsin (1/√ε*r*) and π, are also reflected by the ground plane but only partially by the dielectric-to-air boundary. They progressively leak from the substrate into the air (Fig.2.12), hence their name leaky waves, and eventually contribute to radiation. The leaky waves are also non-uniform plane waves for which the attenuation direction α points downward, which may appear to be rather odd; the amplitude of the waves increases as one moves away from the dielectric surface.

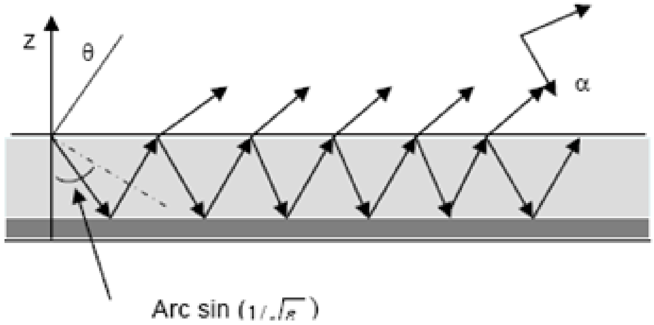


Fig.3.3 Leaky waves

This apparent paradox is easily understood by looking at the figure 2.12 actually, the field amplitude increases as one move away from the substrate because the wave radiates from a point where the signal amplitude is larger. It is well-known that above a critical frequency, this leaky-wave will propagate with little attenuation and that the phase difference between the two radiating edges of the microstrip leads to radiation. However, due to the limits of installation area, such antennas must be terminated in a manner that reduces back reflection. If this is not done, a standing wave is established on the antenna limiting its utility as a leaky-wave antenna in terms of front-to-back ratio and bandwidth.

Since the structure is finite, this apparent divergent behavior can only exist locally, and the wave vanishes abruptly as one crosses the trajectory of the first ray in the figure. In more complex structures made with several layers of different dielectrics, leaky waves can be used to increase the apparent antenna size and thus provide a larger gain. This occurs for favorable stacking arrangements and at a particular frequency. Conversely, leaky waves are not excited in some other multilayer structures.

3.1.3 Guided Waves

The guided waves provide the normal operation of all transmission lines and circuits, in which the electromagnetic fields are mostly concentrated in the volume below the upper conductor. When realizing printed circuits, one locally adds a metal layer on top of the substrate, which modifies the geometry, introducing an additional reflecting boundary. Waves directed into the dielectric located under the upper conductor bounce back and forth on the metal boundaries, which form a parallel plate waveguide. The waves in the metallic guide can only exist for some Particular values of the angle of incidence, forming a discrete set of waveguide modes. On the other hand, this buildup of electromagnetic energy is not favorable for patch antennas, which behave like resonators with a limited frequency bandwidth.

3.2 Analytical Evaluation of a Patch Antenna

The Objectives of antenna analysis are to predict the radiation characteristics such as radiation patterns, gain, and polarization as well as input impedance, bandwidth, mutual coupling, and antenna efficiency. The analysis of microstrip antennas is complicated by the presence of in homogeneity of dielectric and boundary conditions, narrow frequency band characteristics, and wide variety of feed, patch shape, and substrate configurations. The good model has the following basic characteristics:

- It can be used to calculate all impedance and radiation characteristics of the antenna
- Its results are accurate enough for the intended purpose
- It is simple and possible, while providing the proposed accuracy for the impedance and radiation properties.
- It lends itself to interpretation in terms of known physical phenomena.

There are many methods of analysis for microstrip antenna. The most popular methods are the transmission line model, the cavity model, and the full-wave model. The transmission line model is the easiest of all, it gives good physical insight. But it is less accurate and more difficult to model coupling effect of antenna. Compared to the transmission line model, the cavity model is more accurate but at the same time more complex and difficult to model coupling effect. In general, when applied properly, the full wave model is very accurate, and very versatile. and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements, and coupling. However they are the most complex models and usually give less physical insight.

3.2.1 Transmission Line Model

The Transmission line model is the simplest of all, representing the rectangular patch as a parallel-plate transmission line connecting two radiating slots (apertures), each of width *W* and height *h* separated by a transmission line of length L. The microstrip is essentially a non-homogeneous line of two dielectrics, typically the substrate and air.

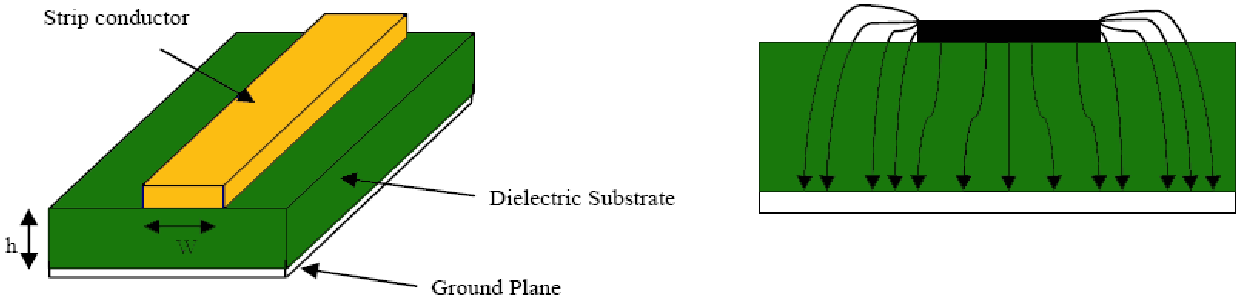


Fig.3.4 Microstrip Line

The Transmission line model is not accurate and lacks versatility. However, it gives a relatively good physical insight into the nature of the patch antenna and the field distribution for all TM$_{00n}$ modes. The slots represent very high-impedance terminations from both sides of the transmission line (almost an open circuit). Thus, we expect this structure to have highly resonant characteristics depending crucially on its length *L* along *z*. The resonant length of the patch, however, is not exactly equal to the physical length due to the fringing effect. The fringing effect makes theeffective electrical length of the patch longer than its physical length, *Leff* >L. Thus, the resonance condition depends on *Leff* , not *L*.

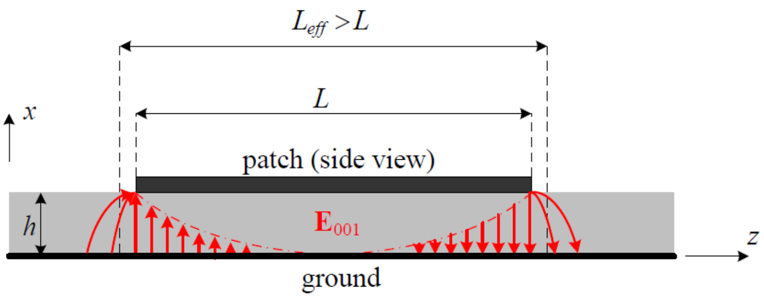


Fig.3.5 Side view of microstrip antenna

Hence, most of the electric field lines reside in the substrate and parts of some lines in air. As a result, this transmission line cannot support pure transverse-electric- magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant (ε_{reff}) must be obtained in order to account for the 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. The expression for ε_{reff} is given by Balanis [9] as:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

Where ε_{reff} = Effective dielectric constant

ε_r = Dielectric constant of substrate

h = Height of dielectric substrate

W = Width of the patch

Consider Figure 2.15 below, which shows a rectangular microstrip 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.

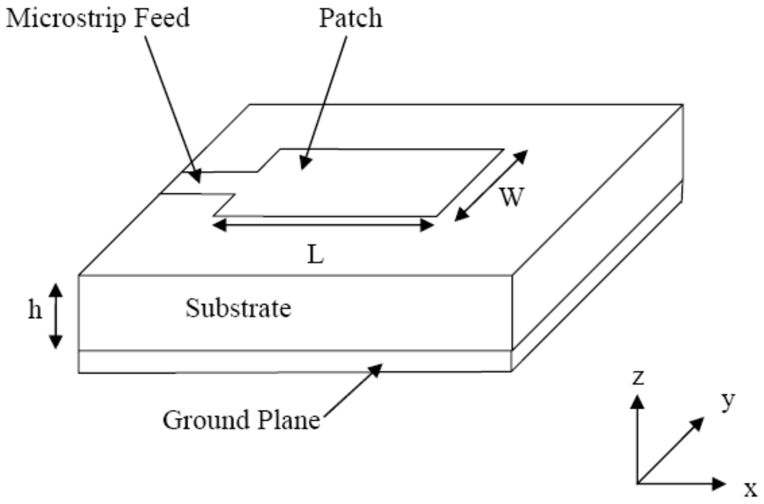


Fig.3.6 Microstrip Patch Antenna

In order to operate in the fundamental TM_{10} mode, the length of the patch must be slightly less than $\lambda/2$ where λ is the wavelength in the dielectric medium and is equal to $\lambda_o/\sqrt{\varepsilon reff}$ where λ_o is the free space wavelength. The TM_{10} mode implies that the field varies one $\lambda/2$ cycle along the length, and there is no variation along the width of the patch. In the Figure 2.16 shown below, the microstrip 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 current is minimum due to the open ends. The fields at the edges can be resolved into normal and tangential components with respect to the ground plane.

It is seen from Figure 3.5 that 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 hence they cancel each other in the broadside direction. The tangential components (seen in Figure 2.15), which are in phase, means that the resulting fields combine to give maximum radiated field normal to the surface of the structure. 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 above the ground plane. The fringing fields along the width can be modeled as radiating slots and electrically the patch of the microstrip 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 Balanis[1][19] as

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

The effective length of the patch L_{eff} now becomes:

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

For a given resonance frequency f_o, the effective length is given by [9] as:

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

For Microstrip patch Antenna, the resonant frequency in TM_{10} is given by

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

Where m and n are modes along L and W respectively.

For efficient radiation, the width W is given by Bahl and Bhartia [15] as:

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

3.2.2 The Cavity Model

The Transmission line model is very limited in its description of the real processes taking place when a patch is excited. it is useful for patches of rectangular design and it ignores field variations along the radiating edges. These disadvantages can be overcome by using the cavity model. A brief overview of this model is given below [19]. The cavity model is a more general model of the patch which imposes open-end conditions at the side edges of the patch. It represents the patch as a dielectric-loaded cavity with:

- electrical walls (above and below), and
- magnetic walls (around the perimeter of the patch.

The magnetic wall is a wall at which

$$\hat{\mathbf{n}} \times \mathbf{H} = 0 \quad \text{(the } \mathbf{H}\text{-field is purely normal)}$$
$$\hat{\mathbf{n}} \cdot \mathbf{E} = 0 \quad \text{(the } \mathbf{E}\text{-field is purely tangential)}$$

Microstrip antenna resembles dielectric loaded cavities, and they exhibit higher order resonances. The normalized fields within the dielectric substrate (between the patch and the ground plane) can be found more accurately by treating that region as a cavity bounded by electric conductors (above and below it) and by magnetic walls (to simulate an open circuit) along the perimeter of the patch. This is an approximate model, which in principle leads to a reactive input impedance (of zero or infinite value of resonance), and it does not radiate any power. However, assuming that the actual fields are approximate to those generated by such a model, the computed pattern, input admittance, and resonant frequencies compare well with measurements.

When the Microstrip patch is energized, a charge distribution is established on the upper and lower surfaces of the patch, as well as on the surface of the ground plane, as shown in figure .

The charge distribution is controlled by two mechanisms: *an attractive and a repulsive mechanism*. The attractive mechanism is between the corresponding opposite charges on the bottom side of the patch and the ground plane, which tends to maintain the charge on the bottom of the patch. The repulsive mechanism is between like charges on the bottom of surface of the patch, which tends to push some charges from the bottom of the patch, around its edges, to its top surface. The movement of these charges creates, corresponding current densities $\mathbf{J}_b$ and $\mathbf{J}_t$, at the bottom and the top surfaces of the patch, respectively, as shown in figure 2.1

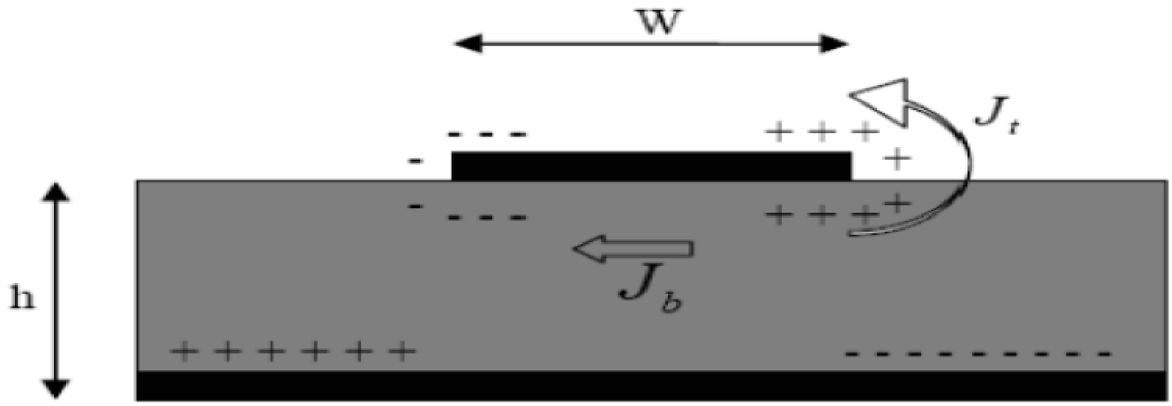


Fig. 3.7 Charge distribution and current density creation on the microstrip patch

Since for most practical microstrips the height to width ratio (*h/W)* is very small, the attractive mechanism dominates and most of the charge concentration and current flow remain underneath the patch. A small amount of current flows around the edges of the patch to its top surface. However this current flow decreases as the *h/W* ratio decreases. In the limit, the current flow to the top would be zero, which ideally would not create any tangential magnetic field components to the edges of the patch. This would allow the four side walls to be modeled by perfect magnetic conducting surfaces which ideally would not disturb the magnetic field and in turn the electric field distributions beneath the patch.

Since in practice there is a finite height to width ratio, although small, the tangential magnetic fields at the edges would not be exactly zero. However, since they will be small, a good approximation to the cavity model is to treat the side walls as perfectly magnetic conducting. This model produces good normalized electric and magnetic field distributions (modes) beneath the patch.

If the microstrip antenna were treated only as a cavity, it would not be sufficient to find the absolute amplitudes of the electric and magnetic fields. In fact by treating the walls of the cavity, as well as the material within it as lossless, the cavity would not radiate and its input impedance would be purely reactive. To account for radiation, a loss mechanism has to be introduced, this is taken into account by radiation resistance R_r and loss resistance R_l. These two resistances allow the input impedances to be complex and for its functions to have complex poles; the imaginary poles representing, through R_r and R_l, the radiation and conduction dielectric losses. To make the microstrip lossy using the cavity model, which would then represent an antenna, the loss is taken into account by introducing an effective loss tangent δ_{eff}.. The effective loss tangent is chosen appropriately to represent the loss mechanism of the cavity, which now behaves as an antenna and is taken as the reciprocal of quality factor Q (δ_{eff}=1/Q).

Because the thickness of the microstrip is usually very small, the waves generated within the dielectric substrate (between the patch and the ground plane) undergo considerable reflections when they arrive at the edge of the patch. Therefore only a small fraction of the incident energy is radiated; thus the antenna is considered to be very inefficient.

3.3.3 Full Wave Solutions-Method of Moments

One of the methods, that provide the full wave analysis for the microstrip patch antenna, is the Method of Moments. In this method, the surface currents are used to model the microstrip patch and the volume polarization currents are used to model the fields in the dielectric slab. It has been shown by J.R. James and P.S. Hall [13] how an integral equation is obtained for these unknown currents and using the Method of Moments, these electric field integral equations are converted into matrix equations which can then be solved by various techniques of algebra to provide the result. A brief overview of the Moment Method described by D. Heberling et al [19] and [5] is given below. The basic form of the equation to be solved by the Method of Moment is:

$$F(g) = h$$

where F is a known linear operator, g is an unknown function, and h is the source or excitation function. The aim here is to find g, when F and h are known. The unknown function g can be expanded as a linear combination of N terms to give:

$$g = \sum_{n=1}^{N} a_n g_n = a_1 g_1 + a_2 g_2 + \ldots\ldots + a_N g_N$$

where a_n is an unknown constant and g_n is a known function usually called a basis or expansion function. Using the linearity property of the operator F, we can write:

$$\sum_{n=1}^{N} a_n F(g_n) = h$$

The basis functions g_n must be selected in such a way, that each $F(g_n)$ in the above equation can be calculated. The unknown constants a_n cannot be determined directly because there are N unknowns, but only one equation. One method of finding these constants is the method of weighted residuals. In this method, a set of trial solutions is established with one or more variable parameters. The residuals are a measure of the difference between the trial solution and the true solution. The variable parameters are selected in a way which guarantees a best fit of the trial functions based on the minimization of the residuals.

CHAPTER-4

ANTENNA PARAMETERS

Important Parameters of Antennas

The performance of the antennas can be gauged with the help of various antenna parameters. These parameters are defined and briefly discussed below.

4.1 Resonant Frequency

The resonance frequency for the (1, 0) mode is given by

$$f_0 = \frac{c}{2L_e\sqrt{\varepsilon_r}}$$

Where *C* is the speed of light in vacuum.

To account for the fringing of the cavity fields at the edges of the patch, the length, the effective length *Le* is chosen as

$$Le = L + 2\Delta L$$

The Hammerstad formula for the fringing extension is [1]

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

Where

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{W}\right)^{-1/2}$$

4.2 Return loss

The Return Loss (RL) is a parameter which indicates the amount of power that is “lost” to the load and does not return as a reflection. As explained in the preceding section, 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 similar to the VSWR to indicate how well the matching between the transmitter and antenna has taken place. The return loss is given by:

$$RL = 10\ logPrPi,$$

Where

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

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

$$Rl = -20 log|г|,$$

and the reflection coefficient г can be expressed as:

$$г=VrVi$$

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

4.3 Gain

The gain of an antenna is the radiation intensity in a given direction divided by the radiation intensity that would be obtained if the antenna radiated all of the power delivered equally to all directions. The definition of gain requires the concept of an isotropic radiator; that is, one that radiates the same power in all directions. An isotropic antenna, however, is just a concept, because all practical antennas must have some directional properties. Nevertheless, the isotropic antenna is very important as a reference. It has a gain of unity (g = 1 or G = 0 dB) in all directions, since all of the power delivered to it is radiated equally well in all directions.

Antenna gain Relates the intensity of an antenna in a given direction to the intensity that would be produced by a hypothetical ideal antenna that radiates equally in all directions (isotropically) and has no losses. Since the radiation intensity from a lossless isotropic antenna equals the power into the antenna divided by a solid angle of 4π steradians, we can write the following equation

$$Gain = 4\pi\left(\frac{\text{Radiation Intensity}}{\text{Antenna Input Power}}\right)$$

$$Gain = 4\pi\left(\frac{\mathrm{U}(\theta,\phi)}{\mathrm{Pin}}\right) \qquad \text{Dimensionless Units.}$$

Although the isotopes are a fundamental reference for antenna gain, another commonly used reference is the dipole. In this case the gain of an ideal (lossless) half wavelength dipole is used. Its gain is 1.64 (G = 2.15 dB) relative to an isotropic radiator.The gain of an antenna is usually expressed in decibels (dB). When the gain is referenced to the isotropic radiator, the units are expressed as dBi; but when referenced to the half-wave dipole, the units are expressed as dBd.

4.4 Directivity

The directivity of an antenna is defined as "the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions". It is therefore a measure of the directional properties of an antenna compared to those of an isotropic antenna.

$$D = U / U_i = 4\pi U / P_{rad}$$

Where *D* is the directivity of the antenna .*U* is the radiation intensity of the antenna. U_i is the radiation intensity of an isotropic source. *P* is the total power radiated.

If the direction of the directivity is not specified. In this case, the direction of the maximum radiation intensity is implied and the maximum directivity is given by [5] as:

$$D_{max} = U_{max} / U_i = 4\pi U_{max} / P_{rad}$$

where D_{max} is the maximum directivity. U_{max} is the maximum radiation intensity

Directivity is a dimensionless quantity, since it is the ratio of two radiation intensities. Hence, it is generally expressed in dBi. The directivity of an antenna can be easily estimated from the radiation pattern of the antenna. An antenna that has a narrow main lobe would have better directivity, then the one which has a broad main lobe, hence it is more directive.

The gain of an antenna is directly related to its directivity, the antenna gain is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. In contrast, directivity is defined as a measure that takes into account only the directional properties of the antenna and therefore it is only influenced by the antenna pattern. However, if we assumed an ideal antenna without losses then Antenna Gain will equal directivity as the antenna efficiency factor equals 1 (100% efficiency). In practice, the gain of an antenna is always less than its directivity.

4.5 Radiation intensity

Radiation Intensity in a given direction is defined as “the power radiated from an antenna per unit solid angle” and is obtained by multiplying the radiation density by the square of the distance. It can be expressed as:

$$U = r^2 W_{rad.}$$

4.6 Radiation Efficiency

The radiation efficiency of the patch antenna is affected not only by conductor and dielectric losses, but also by surface-wave excitation - since the dominant TM0 mode of the grounded substrate will be excited by the patch. As the substrate thickness decreases, the effect of the conductor and dielectric losses becomes more severe, limiting the efficiency. On the other hand, as the substrate thickness increases, the surface-wave power increases, thus limiting the efficiency. Surfacewave excitation is undesirable for other reasons as well, since surface waves contribute to mutual coupling between elements in an array, and also cause undesirable edge diffraction at the edges of the ground plane or substrate, which often contributes to distortions in the pattern and to back radiation. For an air (or foam) substrate there is no surface-wave excitation. In this case, higher efficiency is obtained by making the substrate thicker, to minimize conductor and dielectric losses (making the substrate too thick may lead to difficulty in matching, however, as discussed above). For a substrate with a moderate relative permittivity such as $\varepsilon r = 2.2$, the efficiency will be maximum when the substrate thickness is approximately $\lambda 0 = 0.02$. The radiation efficiency is defined as

$$e_r = \frac{P_{sp}}{P_{Total}} = \frac{P_{sp}}{P_c + P_d + +P_{sw} + P_{sp}}$$

Where *P sp* is the power radiated into space, and the total input power *P total* is given as the sum of *Pc* - the power dissipated by conductor loss, *Pd*- the power dissipated by dielectric loss, and *Psw* – the surface-wave power

4.7 Antenna Efficiency

The total antenna efficiency takes into account all loses in the antenna such as reflections due to mismatch between transmission lines and the antenna, conduction and dielectric loses.

$$\varepsilon total = \varepsilon r \varepsilon c \varepsilon d$$

Where:

- εtotal is the total efficiency of the antenna.
- εr is the efficiency due to mismatch losses.
- εc is the efficiency due to conduction losses.
- εd is the efficiency due to dielectric losses.

the equation as:

$$\epsilon_{total} = \epsilon_r \epsilon_{cd} = \left(1 - |\Gamma|^2\right) \epsilon_{cd}$$

Where Γ is the voltage reflection coefficient and, ε*cd* or (ε*c*ε*d*) is the antenna radiation efficiency which is commonly used to relate the gain and directivity in the antenna.

4.8 Radiation pattern

It is a mathematical function or a graphical representation of the radiation properties of the antenna as the function of space co-ordinates. The radiation pattern of an antenna is peculiar to the type of antenna and electrical characteristics as well as its physical dimensions. It is determined in the far field region and is represented as a function of directional co-ordinates.

The radiation pattern is usually measured in the two principal planes, namely the azimuth and the elevation planes. The radiated power is plotted against the angle that is made with the boresight direction.

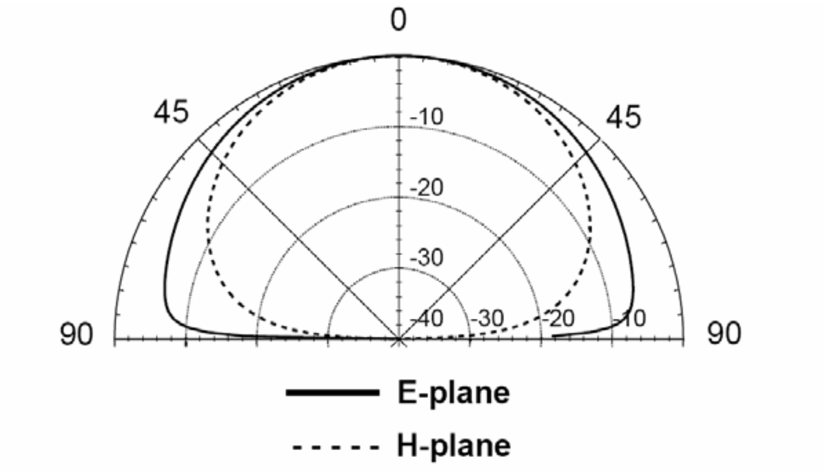


Fig.4.1 Radiation pattern

The radiation pattern can be plotted using rectangular/Cartesian or polar coordinates. The rectangular plots can be read more accurately, but the polar plots give a more pictorial representation and are thus easier to visualize The E-plane pattern is typically broader than the H-plane pattern. The truncation of the ground plane will cause edge diffraction, which tends to degrade the pattern by introducing:

- rippling in the forward direction
- back-radiation

The radiation patterns of a patch may be calculated using either an electric-current model or a magnetic-current model. These models are usually derived assuming that either the electric current on the patch or the electric field at the boundary of the patch corresponds to that of the dominant patch mode for a patch with ideal (magnetic-wall) boundaries. Both models then yield the same result for the far-field pattern when applied to a patch operating at the resonance frequency of the dominant mode of the ideal cavity.

4.9 Input impedance

There are the different kinds of impedance relevant to antenna. One is the terminal impedance of the antenna, another is the characteristic impedance of a transmission line, and the third is wave impedance. Terminal impedance[2] is defined as the ratio of voltage to current at the connections of the antenna (the point where the transmission line is connected). The complex form of Ohm’s law defines impedance as the ratio of voltage across a device to the current flowing through it. The most efficient coupling of energy between an antenna and its transmission line occurs when the characteristic impedance of the transmission line and the terminal impedance of the antenna are the same and have no reactive component. When this is the case, the antenna is considered to be matched to the line. Matching usually requires that the antenna be designed so that it has a terminal impedance of about 50 ohms or 75 ohms to match the common values of available coaxial cable.

The input impedance of patch antenna is in general complex and it includes resonant and non-resonant part. Both real and imaginary parts of the impedance vary as a function of frequency. Ideally, both the resistance and reactance exhibit symmetry about the resonant frequency. Typically, the feed reactance is very small, compared to the resonant resistance for thin substrates.

If the antenna is matched to the transmission line (ZA=ZO), then the input impedance does not depend on the length of the transmission line.

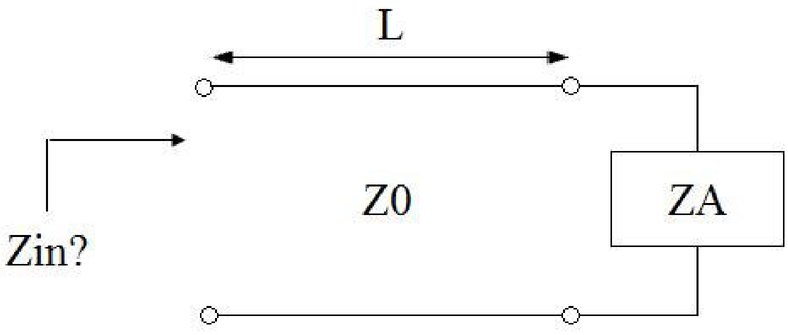


Fig.4.2

If the antenna is not matched, the input impedance will vary widely with the length of the transmission line. And if the input impedance isn't well matched to the source impedance, not very much power will be delivered to the antenna. This power ends up being reflected back to the generator, which can be a problem in itself (especially if high power is transmitted). Hence, we see that having a tuned impedance for an antenna is extremely important. In general, the transmission line will transform the impedance of an antenna, making it very difficult to deliver power, unless the antenna is matched to the transmission line. Consider the situation shown in Figure-3.4 .The impedance is to be measured at the end of a transmission line (with characteristic impedance Z0) and Length L. The end of the transmission line is hooked to an antenna with impedance ZA.

4.10 Voltage Standing Wave Ratio

The standing wave ratio (SWR), also known as the voltage standing wave ratio (VSWR), is not strictly an antenna characteristic, but is used to describe the performance of an antenna when attached to a transmission line. It is a measure of how well the antenna terminal impedance is matched to the characteristic impedance of the transmission line. Specifically, the VSWR is the ratio of the maximum to the minimum RF voltage along the transmission line. The maxima and minima along the lines are caused by partial reinforcement and cancellation of a forward moving RF signal on the transmission line and its reflection from the antenna terminals.

If the antenna terminal impedance exhibits no reactive (imaginary) part and the resistive (real) part is equal to the characteristic impedance of the transmission line, then the antenna and transmission line are said to be matched. It indicates that none of the RF signal sent to the antenna will be reflected at its terminals. There is no standing wave on the transmission line and the VSWR has a value of one. However, if the antenna and transmission line are not matched, then some fraction of the RF signal sent to the antenna is reflected back along the transmission line. This causes a standing wave, characterized by maxima and minima, to exist on the line. In this case, the VSWR has a value greater than one. The VSWR is easily measured with a device and VSWR of 1.5 is considered excellent, while values of 1.5 to 2.0 is considered good, and values higher than 2.0 may be unacceptable.

The VSWR is given by:

$$VSWR = \frac{1 + S_{11}}{1 - S_{11}}$$

4.11 Bandwidth

The bandwidth of an antenna is defined as the range of frequency within the performance of the antenna. The bandwidth increases as the substrate thickness increases (the bandwidth is directly proportional to h if conductor, dielectric, and surface-wave losses are ignored). However, increasing the substrate thickness lowers the Q of the cavity, which increases spurious radiation from the feed, as well as from higher-order modes in the patch cavity. Also, the patch typically becomes difficult to match as the substrate thickness increases beyond a certain point (typically about 0.05 $\lambda 0$). This is especially true when feeding with a coaxial probe, since a thicker substrate results in a larger probe inductance appearing in series with the patch impedance. However, in recent years considerable effort has been spent to improve the bandwidth of the microstrip antenna, in part by using alternative feeding schemes. The aperture-coupled feed of Figure is one scheme that overcomes the problem of probe inductance, at the cost of increased complexity [3].Lowering the substrate permittivity also increases the bandwidth of the patch antenna. However, this has the disadvantage of making the patch larger. Also, because of the patch cavity is lowered, there will usually be increased radiation from higher-order modes, degrading the polarization purity of the radiation.

4.12 Quality factor

The quality (Q) factor of an antenna is a common and simple way to quantify the bandwidth of an antenna [14]. The Q of the antenna is defind as the quotient between the power stored in the reactive field and the radiated power.Quality factor represent the antenna losses. Typically there are radiation, conduction, dielectric and surface wave losses.

$$\frac{1}{Q_t} = \frac{1}{Q_{rad}} + \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_{sc}}$$

Where;

Q_t=Total quality factor, Q_{rad}=Quality factor by radiation losses, Q_c=Quality factor by conduction losses, Q_{dm}=Quality factor by dielectric losses, Q_{sc}=Quality factor by surface wave

The quality factor, bandwidth and efficiency are antenna figures-of-merit, which are interrelated, and there is no complete freedom to independently optimize each one. Generally *Q* is defined in terms of the ratio of the energy stored in the resonator to the energy
being lost in one cycle.

$$Q = 2\pi \times \frac{\text{Energy Stored}}{\text{Energy dissipated per cycle}}.$$

The factor of 2π is used to keep this definition of *Q* consistent (for high values of *Q*) with the second definition.

$$Q = \frac{f_r}{\Delta f} = \frac{\omega_r}{\Delta\omega},$$

Where f_r is the resonant frequency, Δf is the bandwidth, ω_r is the angular resonant frequency, and $\Delta\omega$ is the angular bandwidth. The definition of Q in terms of the ratio of the energy stored to the energy dissipated per cycle can be rewritten as

$$Q = \omega \times \frac{\text{Energy Stored}}{\text{Power Loss}}$$

Physically speaking, *Q* is 2π times the ratio of the total energy stored divided by the energy lost in a single cycle or equivalently the ratio of the stored energy to the energy dissipated per one radian of the oscillation.

CHAPTER-5

ANALYSIS OF CROSS SHAPED MICROSTRIP ANTENNA WITH DIFFERENT SUBSTRATES

5.1 Introduction

A substrate materials play an important role in antenna design, A simple method that can be employed to modify the different properties of the antenna is by changing the substrate; as height (thickness)and dielectric constant of the substrate influence the antenna properties.

The substrate in microstrip antenna is primarily required for giving mechanical strength to antenna. The dielectric used is also responsible for degraded electrical properties of antenna as the surface waves produced on the dielectric extract a part of total power available for direct radiation (space waves)

5.2 Criteria for Substrate Selection

1) surface-wave excitation
2) dispersion of the dielectric constant and loss tangent of the substrate
3) copper loss
4) anisotropy in the substrate
5) effects of temperature, humidity, and aging
6) mechanical requirements: conformability, machinability, solderability, weight, elasticity, etc.
7) cost.

The first 3 factors are of special concern in the millimeter-wave range (f > 30 GHz).

There are numerous substrates that can be used for the design of microstrip antennas with their dielectric constants usually in the range of $2.2 \leq \varepsilon r \leq 12$. The low dielectric constant εr is about 2.2 to 3, the medium around 6.15 and the high approximately above 10.5. Normally, thick substrates with low dielectric constants are often used as it provides better efficiency, larger bandwidth and loosely bound fields for radiation into space. However, it would also result in a larger antenna size.

On the other hand using thin substrates with higher dielectric constants would result in smaller antenna size. The drawbacks are that it is less efficient and has relatively smaller bandwidths. Therefore, there must be a design trade-off between the antenna size and good antenna performance.

In this thesis study has been conducted on cross shaped slot in first quaderent of compact microstrip antenna with several different commonly available dielectrics as its substrate. The proposed antenna can be used for WLAN applications and Road Vehicle Communications. Different types of substrates which are used in this thesis are given below: Foam, Duroid , Benzo-cyclo-buten, Roger 4350, Epoxy ,FR4 ,Glass, Duroid 6010 etc.

5.3 Design Specifications

The three essential parameters for the design of a Microstrip Patch Antenna are:

- ➢ Frequency of operation (*fo*): The resonant frequency of the antenna must be selected appropriately. The Mobile Communication Systems uses the frequency range from 1800-5600 MHz. Hence the antenna designed must be able to operate in this frequency range. The resonant frequency selected for this design is 2.091 GHz.

- ➢ Dielectric constant of the substrate (εr): The dielectric material selected for antenna in this design is Benzo cyclo buten which has a dielectric constant of 2.6. A substrate with a high dielectric constant has been selected since it reduces the dimensions of the antenna.

- ➢ Height of dielectric substrate (*h*): For the microstrip patch antenna to be used in cellular phones, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate is selected as 1.6 mm.

Hence, the essential parameters for the design are:

- fo = 2.091GHz
- εr = 2.6
- h = 1.6 mm

A Cross shaped slot cut in first quadrent of compact microstrip antenna with different types of substrate which have different dielectric constant (ε*r)*.but they have fixed Thickness which is 1.6 mm. Their results are simulated with the help of IE3D Software. IE3D[24] is a full-wave electromagnetic simulator based on the method of moments. It analyzes 3D and multilayer structures of general shapes. It has been widely used in the design of MICs, RFICs, patch antennas, wire antennas, and other RF/wireless antennas. It can be used to calculate and plot the *S*11 parameters, VSWR, smith chart as well as the radiation patterns and many more parameters.

5.4 Simulation Setup and Results using IE3D Software

IE3D is an integrated full-wave electromagnetic simulation and optimization package for the analysis and design of 3-dimensional microstrip antennas and high frequency printed circuits and digital circuits, such as microwave and millimeter wave integrated circuits (MMICS) and high speed printed circuit boards (PCB). IE3D has been adopted as an industrial standard in planar and 3-dimensional electromagnetic simulation. It is technology for electromagnetic simulation to yield high accuracy analysis and design of complicated microwave and RF printed circuit, antennas, high speed digital circuits and other electronic components. The IE3D has become the most versatile ,easy to use, efficient and accurate electromagnetic simulation tool. The IE3D package consists of the following major application programs:

- Layout editor for the construction of a geometery,and post processor for current display and pattern calculation
- Electromagnetic simulator or simulation engine for numerical analysis.
- Schematic editor for parameter display and nodal circuit simulation.
- Post processor for radiation patterns.
- The object oriented 2nd IE3D interface for parameterized geometry construction.
- Post processor for display of current distribution and field distribution.

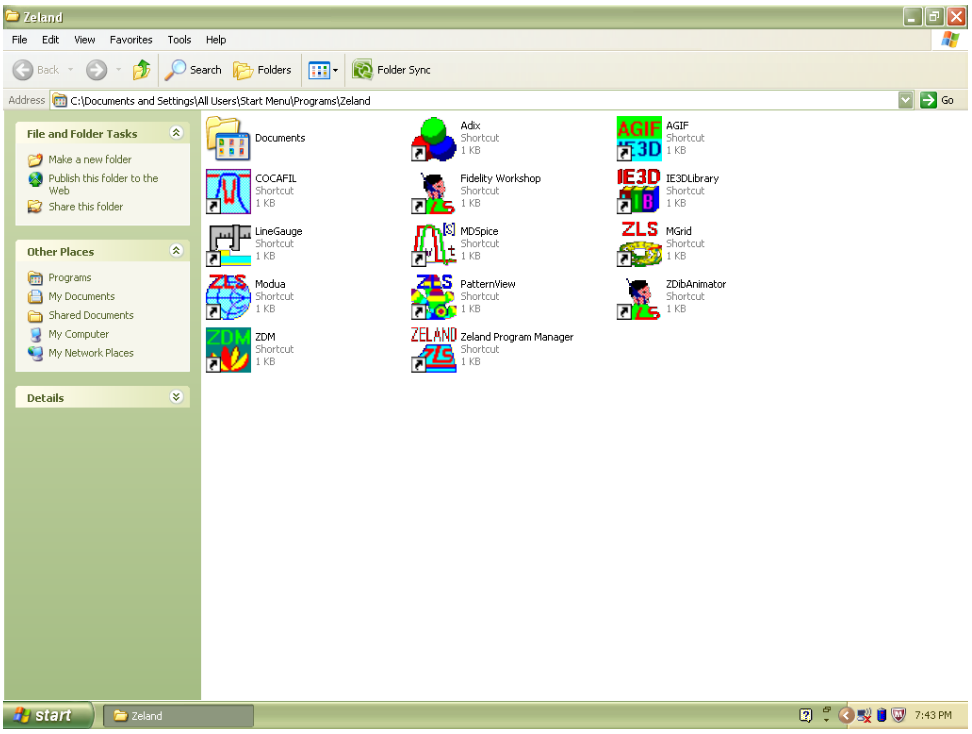
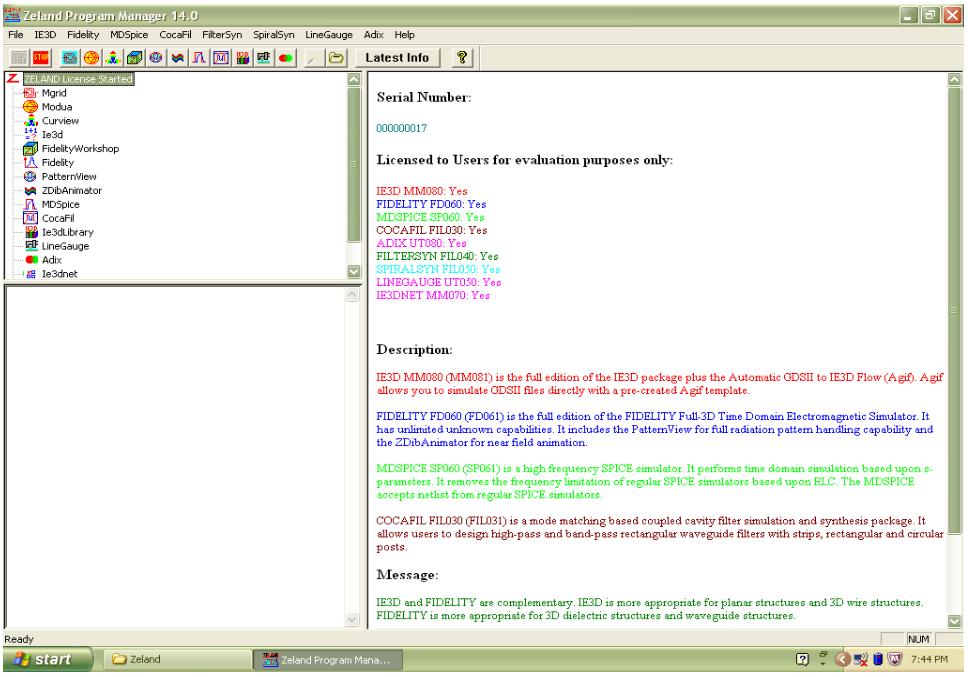


Fig 5.1 Click on zeland Program Manger



Serial Number:

000000017

Licensed to Users for evaluation purposes only:

IE3D MM080: Yes
FIDELITY FD060: Yes
MDSPICE SP060: Yes
COCAFIL FIL030: Yes
ADIX UT080: Yes
FILTERSYN FIL040: Yes
SPIRALSYN FIL050: Yes
LINEGAUGE UT050: Yes
IE3DNET MM070: Yes

Description:

IE3D MM080 (MM081) is the full edition of the IE3D package plus the Automatic GDSII to IE3D Flow (Agif). Agif allows you to simulate GDSII files directly with a pre-created Agif template.

FIDELITY FD060 (FD061) is the full edition of the FIDELITY Full-3D Time Domain Electromagnetic Simulator. It has unlimited unknown capabilities. It includes the PatternView for full radiation pattern handling capability and the ZDibAnimator for near field animation.

MDSPICE SP060 (SP061) is a high frequency SPICE simulator. It performs time domain simulation based upon s-parameters. It removes the frequency limitation of regular SPICE simulators based upon RLC. The MDSPICE accepts netlist from regular SPICE simulators.

COCAFIL FIL030 (FIL031) is a mode matching based coupled cavity filter simulation and synthesis package. It allows users to design high-pass and band-pass rectangular waveguide filters with strips, rectangular and circular posts.

Message:

IE3D and FIDELITY are complementary. IE3D is more appropriate for planar structures and 3D wire structures. FIDELITY is more appropriate for 3D dielectric structures and waveguide structures.

Fig 5.2 Double click on mgrid.

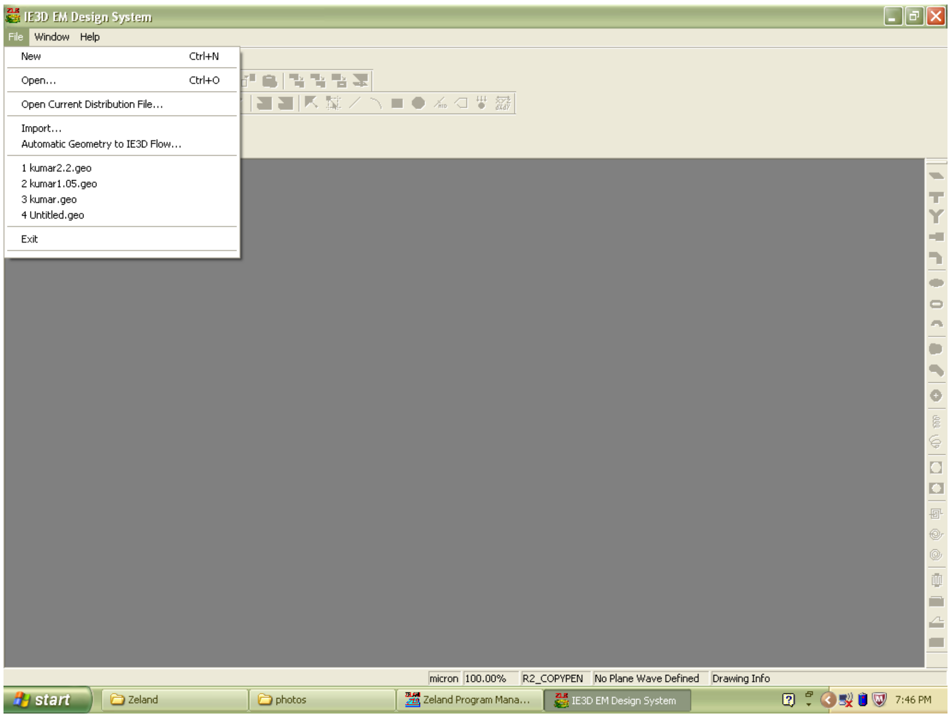
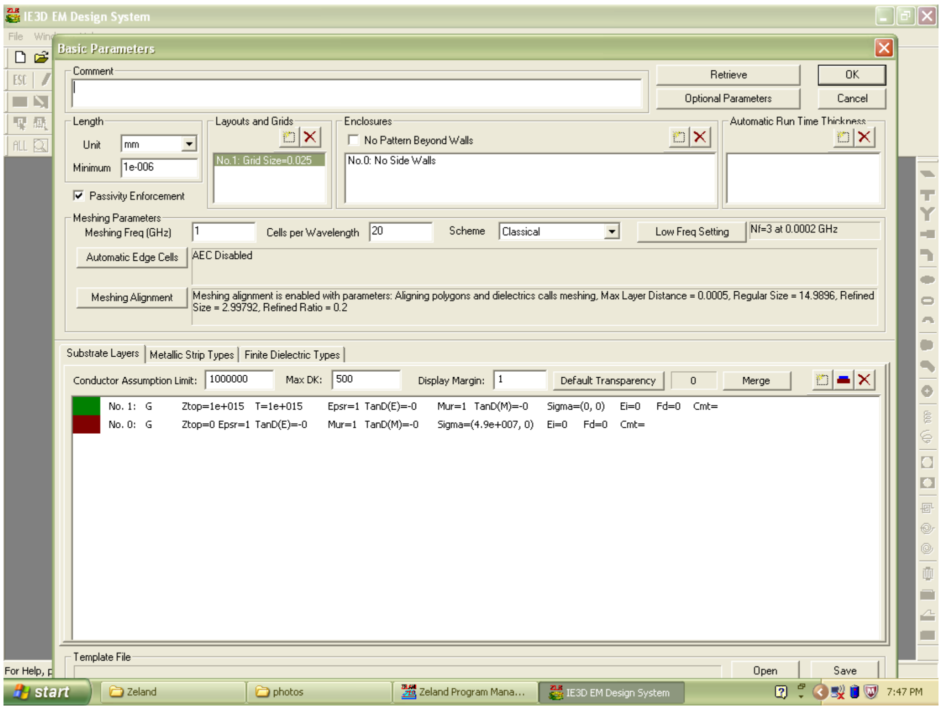


Fig 5.3 Open New File



Comment:

Length
Unit: mm
Minimum: 1e-006

☑ Passivity Enforcement

Layouts and Grids: No.1: Grid Size=0.025

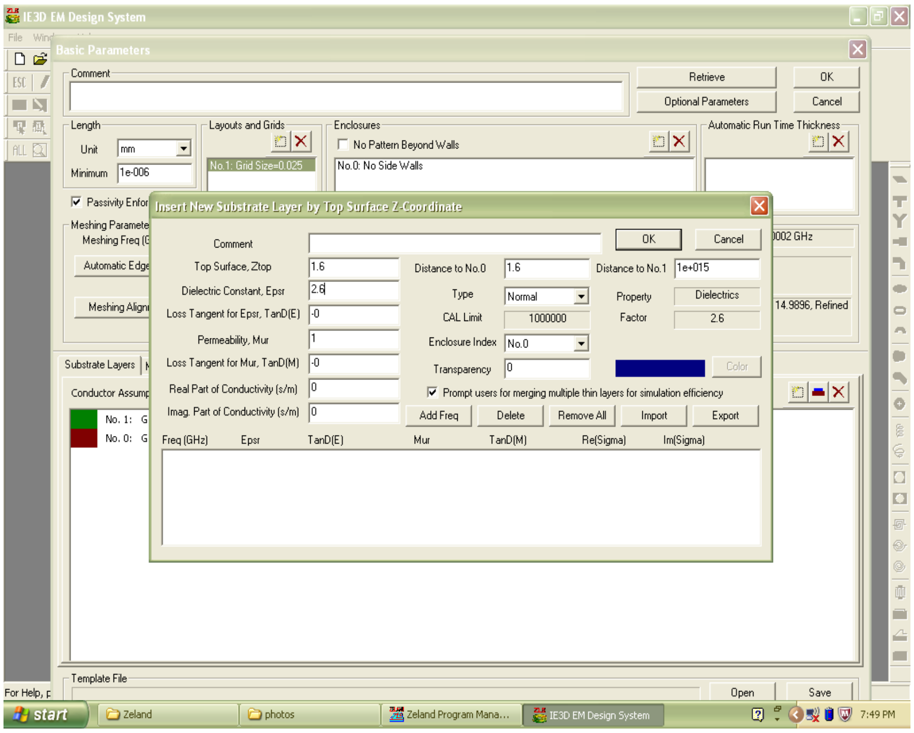
Enclosures: ☐ No Pattern Beyond Walls
No.0: No Side Walls

Meshing Parameters
Meshing Freq (GHz): 1
Cells per Wavelength: 20
Scheme: Classical
Nf=3 at 0.0002 GHz
AEC Disabled
Meshing alignment is enabled with parameters: Aligning polygons and dielectrics calls meshing, Max Layer Distance = 0.0005, Regular Size = 14.9896, Refined Size = 2.99792, Refined Ratio = 0.2

Conductor Assumption Limit: 1000000
Max DK: 500
Display Margin: 1
0

🟩 No. 1: G Ztop=1e+015 T=1e+015 Epsr=1 TanD(E)=-0 Mur=1 TanD(M)=-0 Sigma=(0, 0) Ei=0 Fd=0 Cmt=
🟥 No. 0: G Ztop=0 Epsr=1 TanD(E)=-0 Mur=1 TanD(M)=-0 Sigma=(4.9e+007, 0) Ei=0 Fd=0 Cmt=

Fig 5.4 Basic Parameter

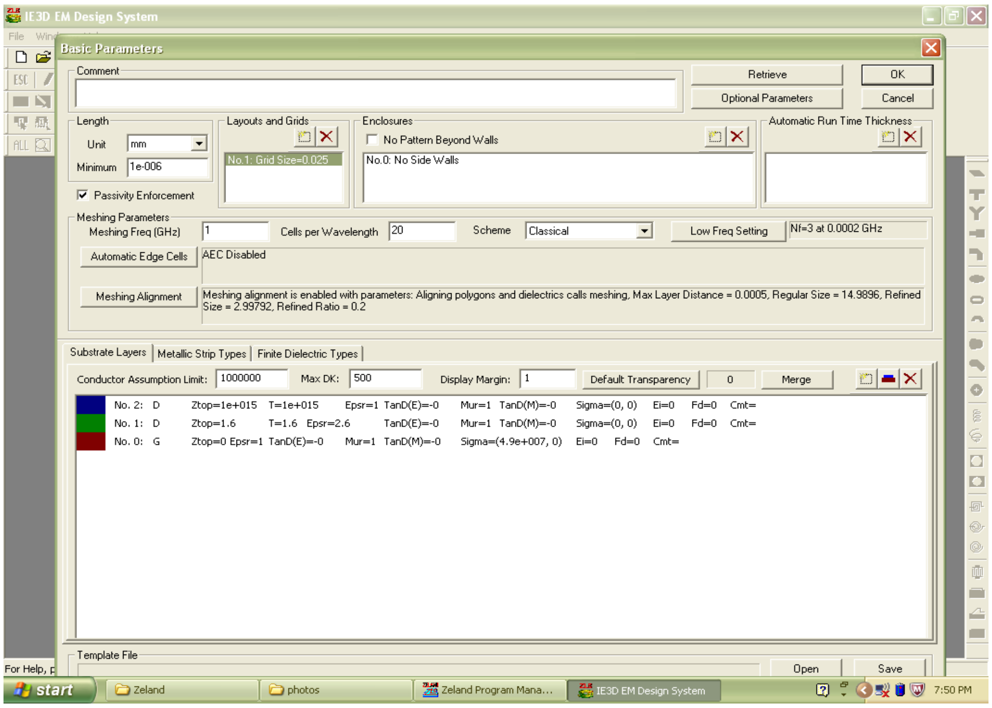


Insert New Substrate Layer by Top Surface Z-Coordinate

Comment:
Top Surface, Ztop: 1.6
Dielectric Constant, Epsr: 2.6
Loss Tangent for Epsr, TanD(E): -0
Permeability, Mur: 1
Loss Tangent for Mur, TanD(M): -0
Real Part of Conductivity (s/m): 0
Imag. Part of Conductivity (s/m): 0
Distance to No.0: 1.6
Distance to No.1: 1e+015
Type: Normal
CAL Limit: 1000000
Enclosure Index: No.0
Transparency: 0
Property: Dielectrics
Factor: 2.6
☑ Prompt users for merging multiple thin layers for simulation efficiency

Length: Unit mm, Minimum 1e-006
Layouts and Grids: No.1: Grid Size=0.025
Enclosures: ☐ No Pattern Beyond Walls; No.0: No Side Walls

Fig 5.5 Define Substrate Parameters Thickness-1.6, Dielectric Constant-2.6



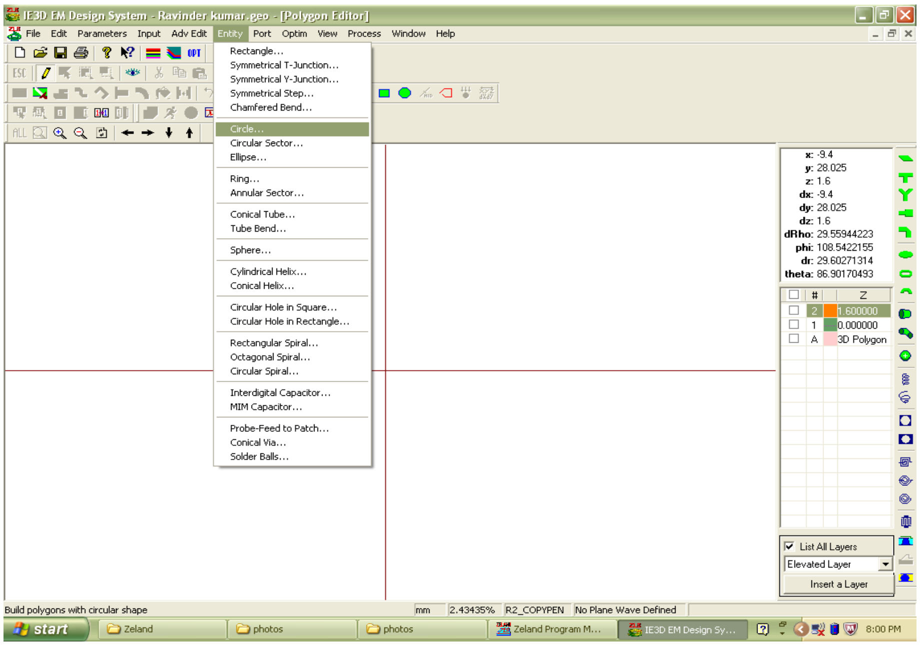
Length: Unit mm, Minimum 1e-006
☑ Passivity Enforcement
Layouts and Grids: No.1: Grid Size=0.025
Enclosures: ☐ No Pattern Beyond Walls; No.0: No Side Walls

Meshing Parameters
Meshing Freq (GHz): 1
Cells per Wavelength: 20
Scheme: Classical
Nf=3 at 0.0002 GHz
AEC Disabled
Meshing alignment is enabled with parameters: Aligning polygons and dielectrics calls meshing, Max Layer Distance = 0.0005, Regular Size = 14.9896, Refined Size = 2.99792, Refined Ratio = 0.2

Substrate Layers | Metallic Strip Types | Finite Dielectric Types
Conductor Assumption Limit: 1000000
Max DK: 500
Display Margin: 1
Default Transparency: 0

```
No. 2:  D    Ztop=1e+015  T=1e+015   Epsr=1  TanD(E)=-0   Mur=1  TanD(M)=-0   Sigma=(0, 0)   Ei=0   Fd=0   Cmt=
No. 1:  D    Ztop=1.6     T=1.6  Epsr=2.6    TanD(E)=-0   Mur=1  TanD(M)=-0   Sigma=(0, 0)   Ei=0   Fd=0   Cmt=
No. 0:  G    Ztop=0 Epsr=1  TanD(E)=-0   Mur=1  TanD(M)=-0   Sigma=(4.9e+007, 0)   Ei=0   Fd=0   Cmt=
```

Fig. 5.6 Basic Parameters dialog box

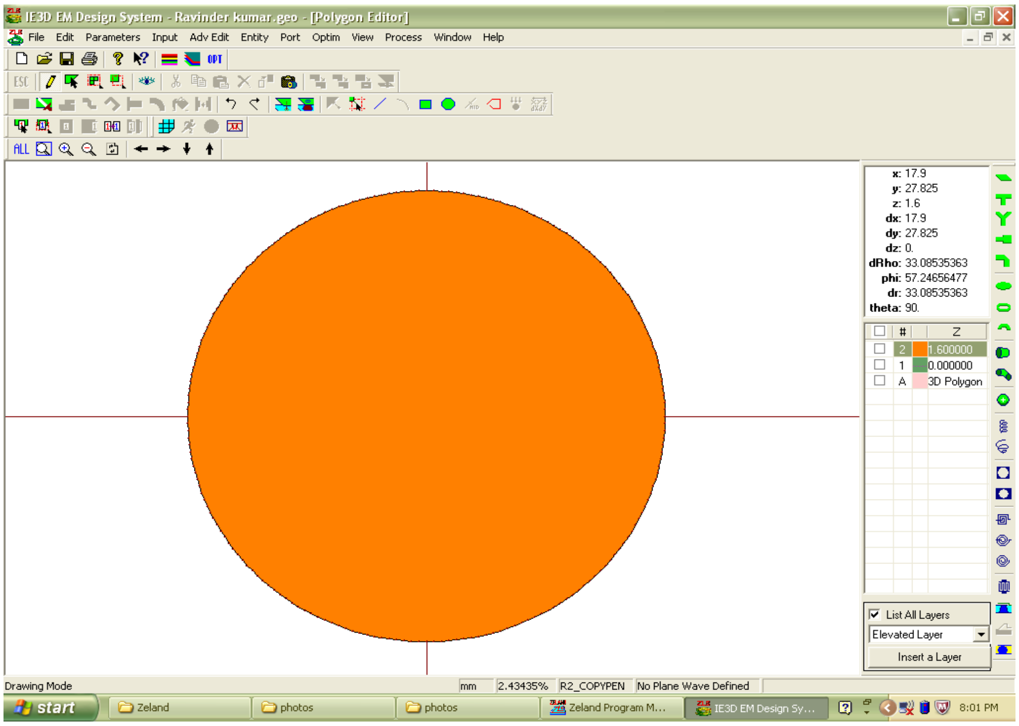


x: -9.4
y: 28.025
z: 1.6
dx: -9.4
dy: 28.025
dz: 1.6
dRho: 29.55944223
phi: 108.5422155
dr: 29.60271314
theta: 86.90170493

#	Z
2	1.600000
1	0.000000
A	3D Polygon

Build polygons with circular shape | mm | 2.43435% | R2_COPYPEN | No Plane Wave Defined

Fig. 5.7 Geometry – Insert Circle

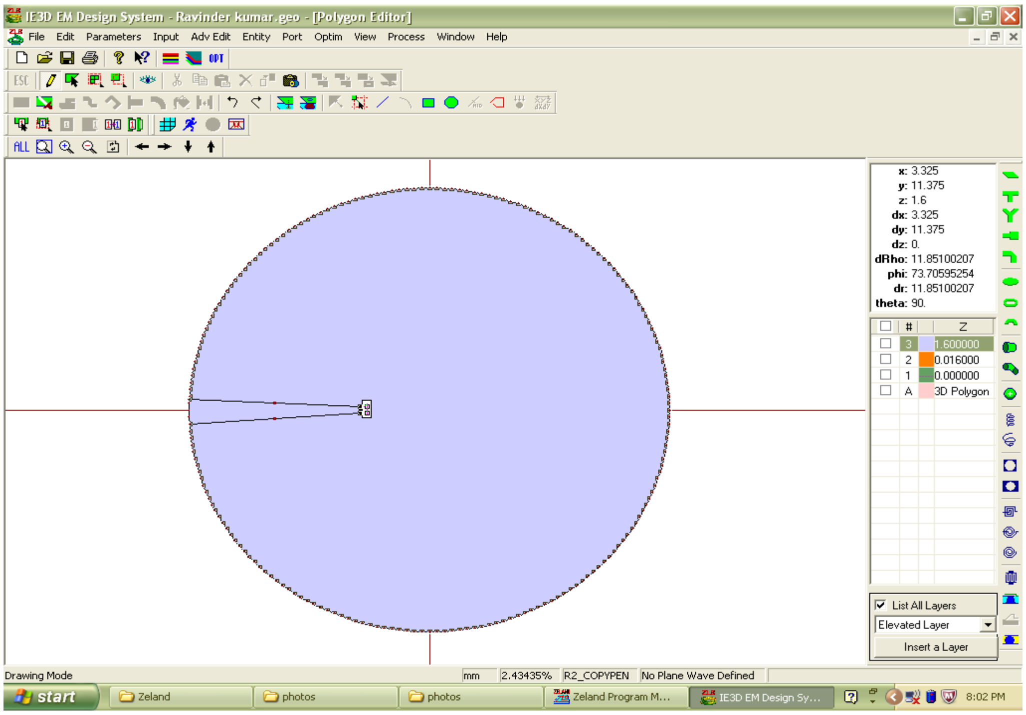


x: 17.9
y: 27.825
z: 1.6
dx: 17.9
dy: 27.825
dz: 0.
dRho: 33.08535363
phi: 57.24656477
dr: 33.08535363
theta: 90.

#	Z
2	1.600000
1	0.000000
A	3D Polygon

Drawing Mode | mm | 2.43435% | R2_COPYPEN | No Plane Wave Defined

Fig. 5.8 Geometry-Circle with Radius=24.8mm


IE3D EM Design System - Ravinder kumar.geo - [Polygon Editor]

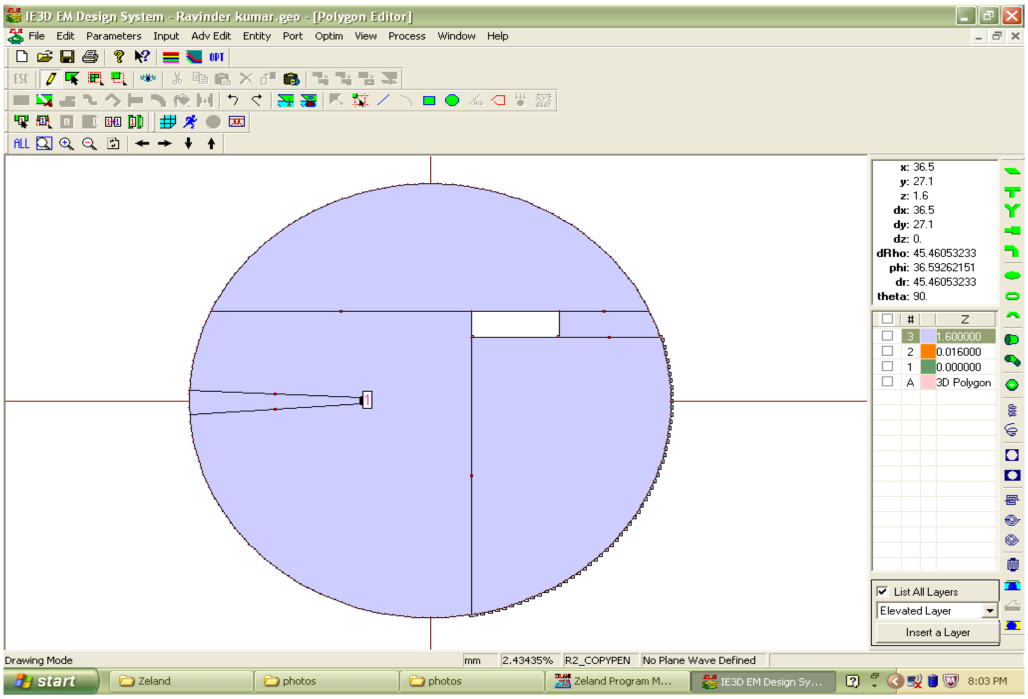
x: 3.325
y: 11.375
z: 1.6
dx: 3.325
dy: 11.375
dz: 0.
dRho: 11.85100207
phi: 73.70595254
dr: 11.85100207
theta: 90.

☐	#	Z
☐	3	1.600000
☐	2	0.016000
☐	1	0.000000
☐	A	3D Polygon

☑ List All Layers
Elevated Layer

Drawing Mode | mm | 2.43435% | R2_COPYPEN | No Plane Wave Defined

Fig. 5.9 Geometry-circle with feeding point, x= -6.8,y=0;


IE3D EM Design System - Ravinder kumar.geo - [Polygon Editor]

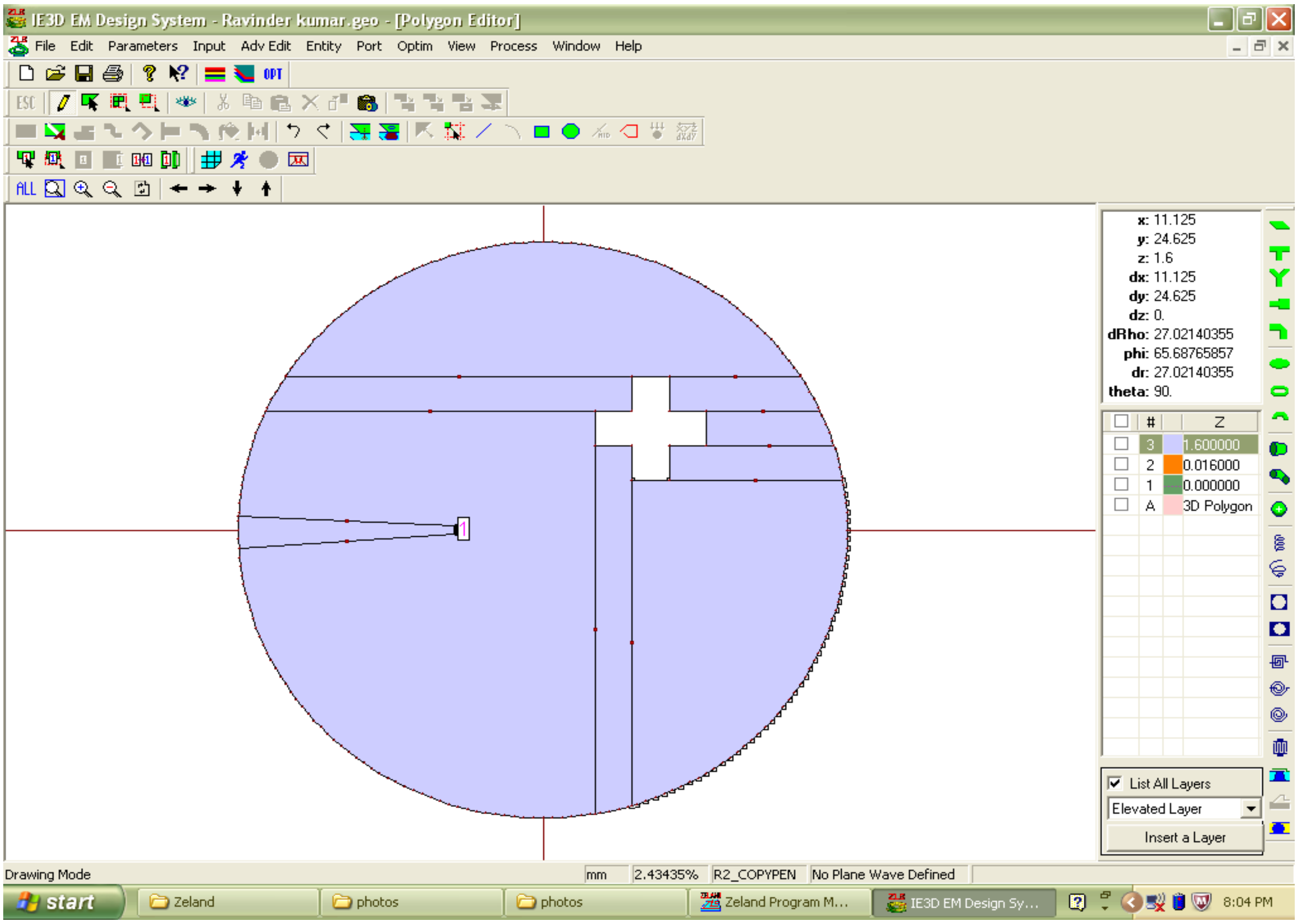
x: 36.5
y: 27.1
z: 1.6
dx: 36.5
dy: 27.1
dz: 0.
dRho: 45.46053233
phi: 36.59262151
dr: 45.46053233
theta: 90.

☐	#	Z
☐	3	1.600000
☐	2	0.016000
☐	1	0.000000
☐	A	3D Polygon

☑ List All Layers
Elevated Layer

Drawing Mode | mm | 2.43435% | R2_COPYPEN | No Plane Wave Defined

Fig. 5.10 Geometry- Slot cut in first quaderent



x: 11.125
y: 24.625
z: 1.6
dx: 11.125
dy: 24.625
dz: 0.
dRho: 27.02140355
phi: 65.68765857
dr: 27.02140355
theta: 90.

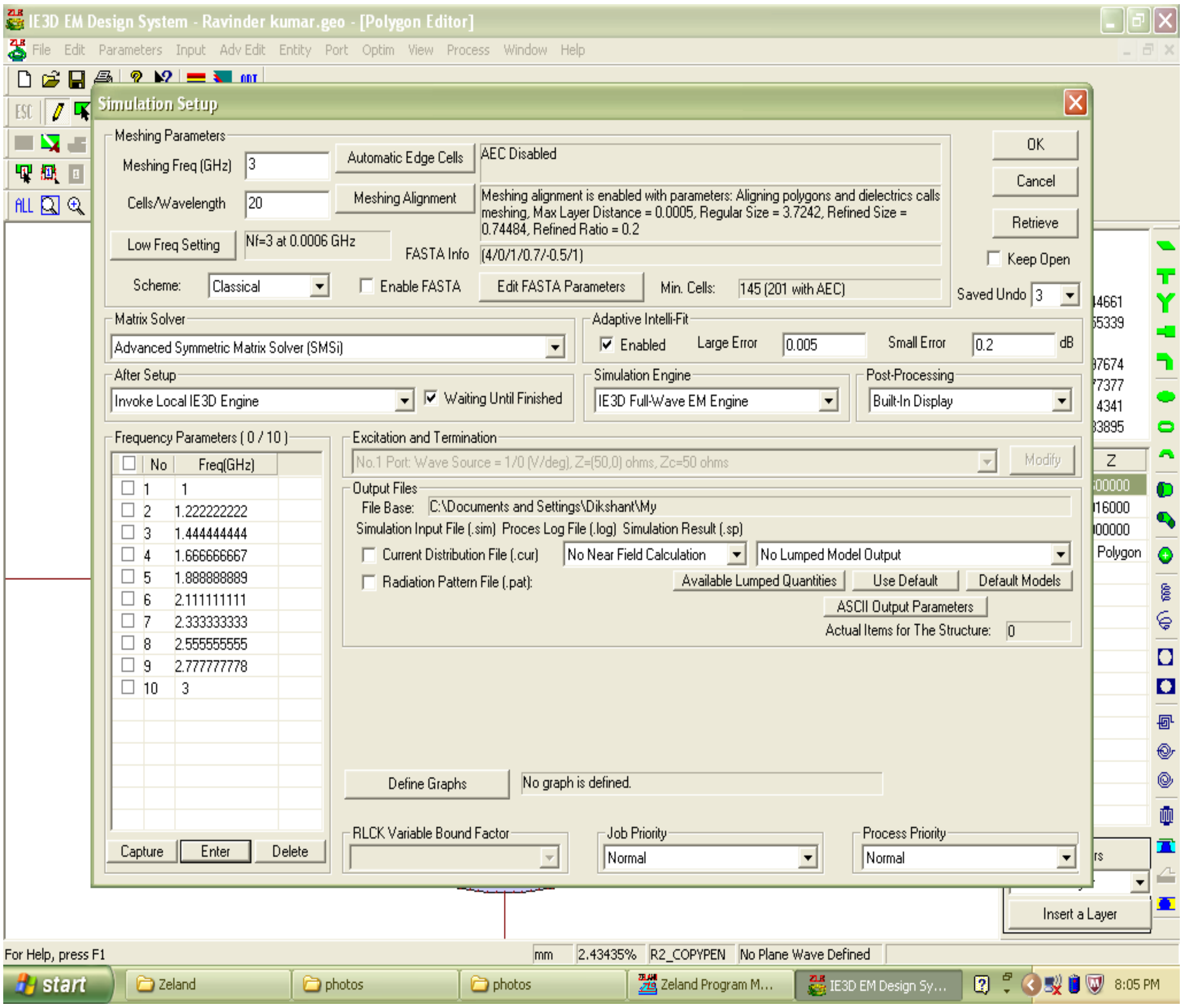
☐	#	Z
☐	3	1.600000
☐	2	0.016000
☐	1	0.000000
☐	A	3D Polygon

☑ List All Layers

Elevated Layer

Drawing Mode | mm | 2.43435% | R2_COPYPEN | No Plane Wave Defined

Fig. 5.11 Geometry- Cross Shaped Slot cut in first quaderent



Meshing Parameters

Meshing Freq (GHz) 3

Cells/Wavelength 20

AEC Disabled

Meshing alignment is enabled with parameters: Aligning polygons and dielectrics calls meshing, Max Layer Distance = 0.0005, Regular Size = 3.7242, Refined Size = 0.74484, Refined Ratio = 0.2

Nf=3 at 0.0006 GHz

FASTA Info (4/0/1/0.7/-0.5/1)

Scheme: Classical

☐ Enable FASTA

Min. Cells: 145 (201 with AEC)

☐ Keep Open

Saved Undo 3

Matrix Solver: Advanced Symmetric Matrix Solver (SMSi)

Adaptive Intelli-Fit: ☑ Enabled Large Error 0.005 Small Error 0.2 dB

After Setup: Invoke Local IE3D Engine ☑ Waiting Until Finished

Simulation Engine: IE3D Full-Wave EM Engine

Post-Processing: Built-In Display

Frequency Parameters (0 / 10)

☐ No	Freq(GHz)
☐ 1	1
☐ 2	1.222222222
☐ 3	1.444444444
☐ 4	1.666666667
☐ 5	1.888888889
☐ 6	2.111111111
☐ 7	2.333333333
☐ 8	2.555555555
☐ 9	2.777777778
☐ 10	3

Excitation and Termination: No.1 Port: Wave Source = 1/0 (V/deg), Z=(50,0) ohms, Zc=50 ohms

Output Files

File Base: C:\Documents and Settings\Dikshant\My

Simulation Input File (.sim) Proces Log File (.log) Simulation Result (.sp)

☐ Current Distribution File (.cur) No Near Field Calculation No Lumped Model Output

☐ Radiation Pattern File (.pat):

Actual Items for The Structure: 0

No graph is defined.

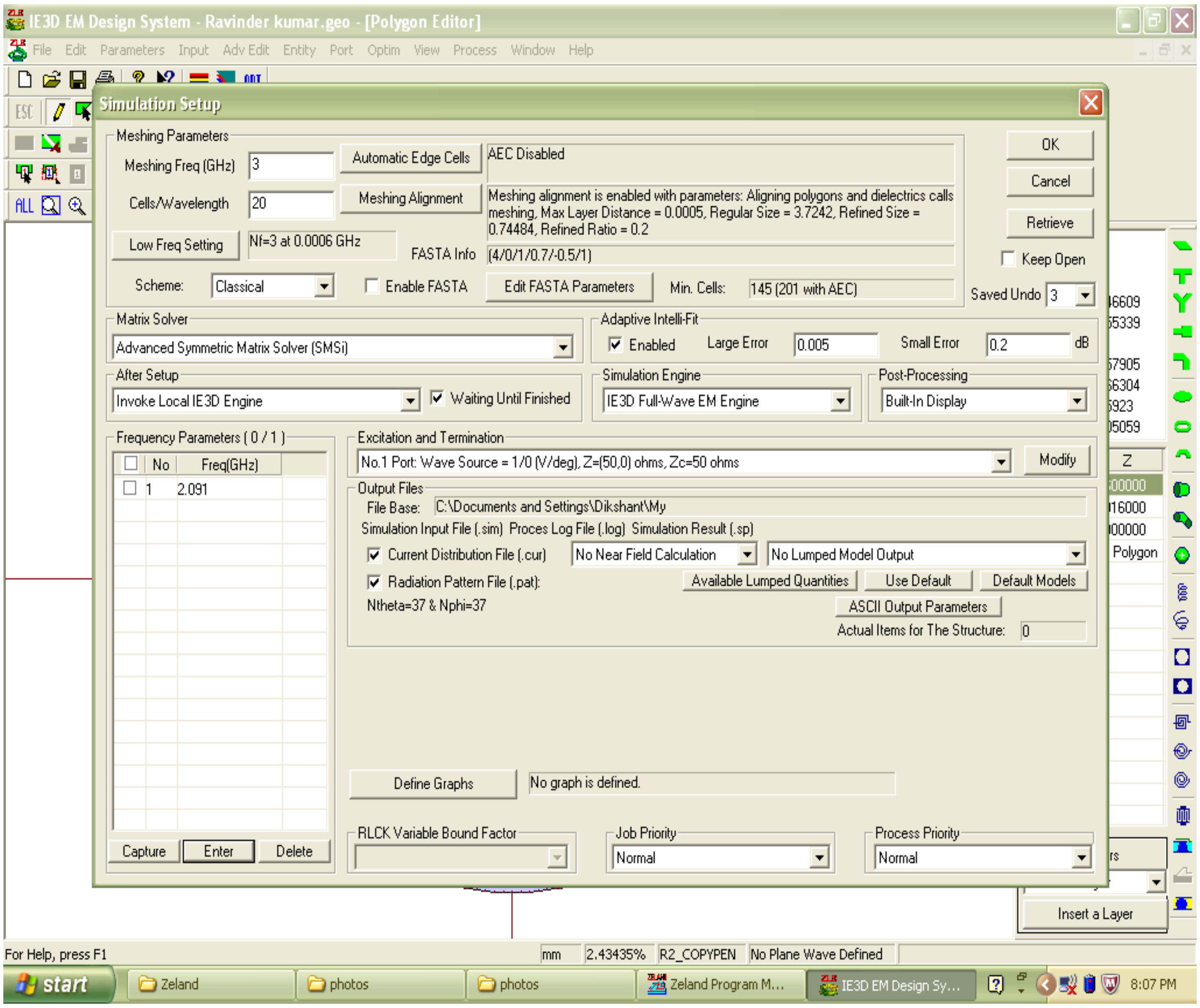
RLCK Variable Bound Factor

Job Priority: Normal

Process Priority: Normal

For Help, press F1 mm 2.43435% R2_COPYPEN No Plane Wave Defined

Fig. 5.12 Optimization Setup



Meshing Parameters

Meshing Freq (GHz) 3

Cells/Wavelength 20

AEC Disabled

Meshing alignment is enabled with parameters: Aligning polygons and dielectrics calls meshing, Max Layer Distance = 0.0005, Regular Size = 3.7242, Refined Size = 0.74484, Refined Ratio = 0.2

Nf=3 at 0.0006 GHz

FASTA Info (4/0/1/0.7/-0.5/1)

Scheme: Classical

☐ Enable FASTA

Min. Cells: 145 (201 with AEC)

☐ Keep Open

Saved Undo 3

Matrix Solver: Advanced Symmetric Matrix Solver (SMSi)

Adaptive Intelli-Fit: ☑ Enabled Large Error 0.005 Small Error 0.2 dB

After Setup: Invoke Local IE3D Engine ☑ Waiting Until Finished

Simulation Engine: IE3D Full-Wave EM Engine

Post-Processing: Built-In Display

Frequency Parameters (0 / 1)

☐ No	Freq(GHz)
☐ 1	2.091

Excitation and Termination: No.1 Port: Wave Source = 1/0 (V/deg), Z=(50,0) ohms, Zc=50 ohms

Output Files

File Base: C:\Documents and Settings\Dikshant\My

Simulation Input File (.sim) Proces Log File (.log) Simulation Result (.sp)

☑ Current Distribution File (.cur) No Near Field Calculation No Lumped Model Output

☑ Radiation Pattern File (.pat):

Ntheta=37 & Nphi=37

Actual Items for The Structure: 0

No graph is defined.

RLCK Variable Bound Factor

Job Priority: Normal

Process Priority: Normal

For Help, press F1 mm 2.43435% R2_COPYPEN No Plane Wave Defined

Fig.5.13 Simulation Setup

After complete simulation we have simulated results.

5.5 Simulation Results

In this thesis we used different types of substrate which have different types of dielectric constant. All of them have same thickness is about 1.6 mm. Their simulated results with cross shaped slot in first quadrant are given below:

5.5.1 Material- Form; Electrical Permittivity(εr): 1.05

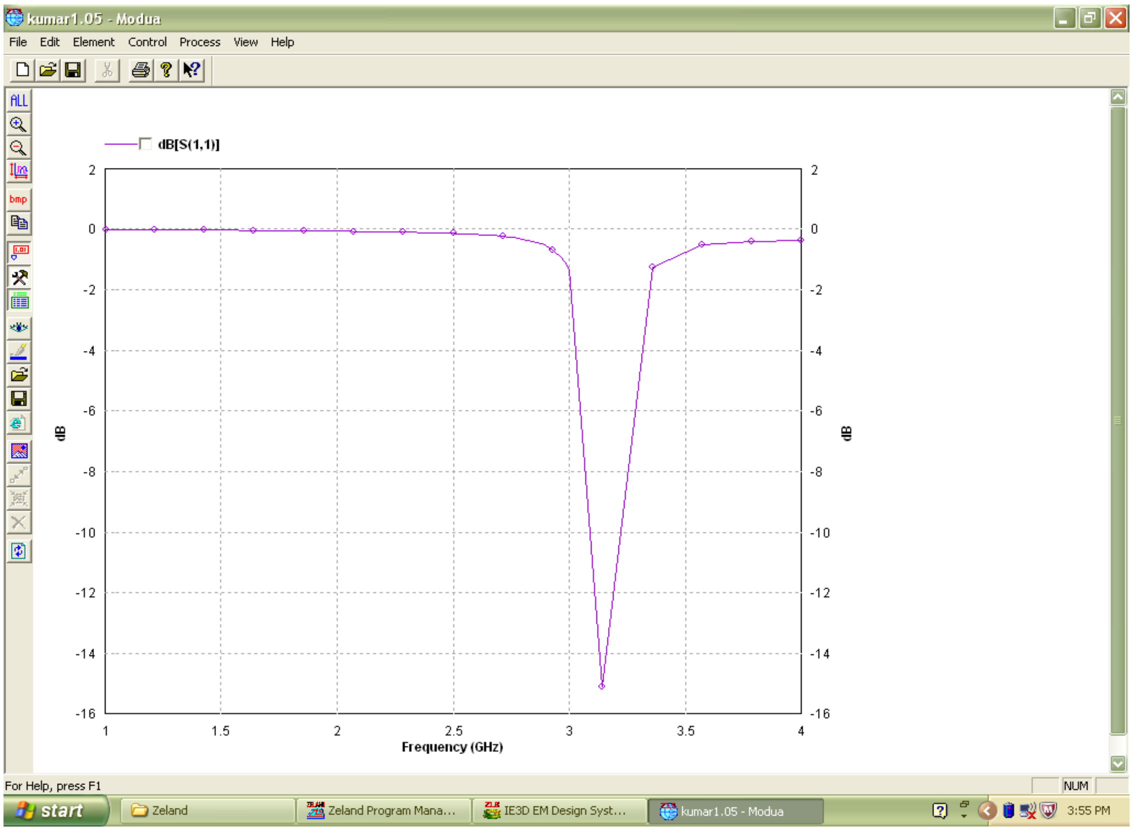


Fig. 5.14 Return Loss vs frequency

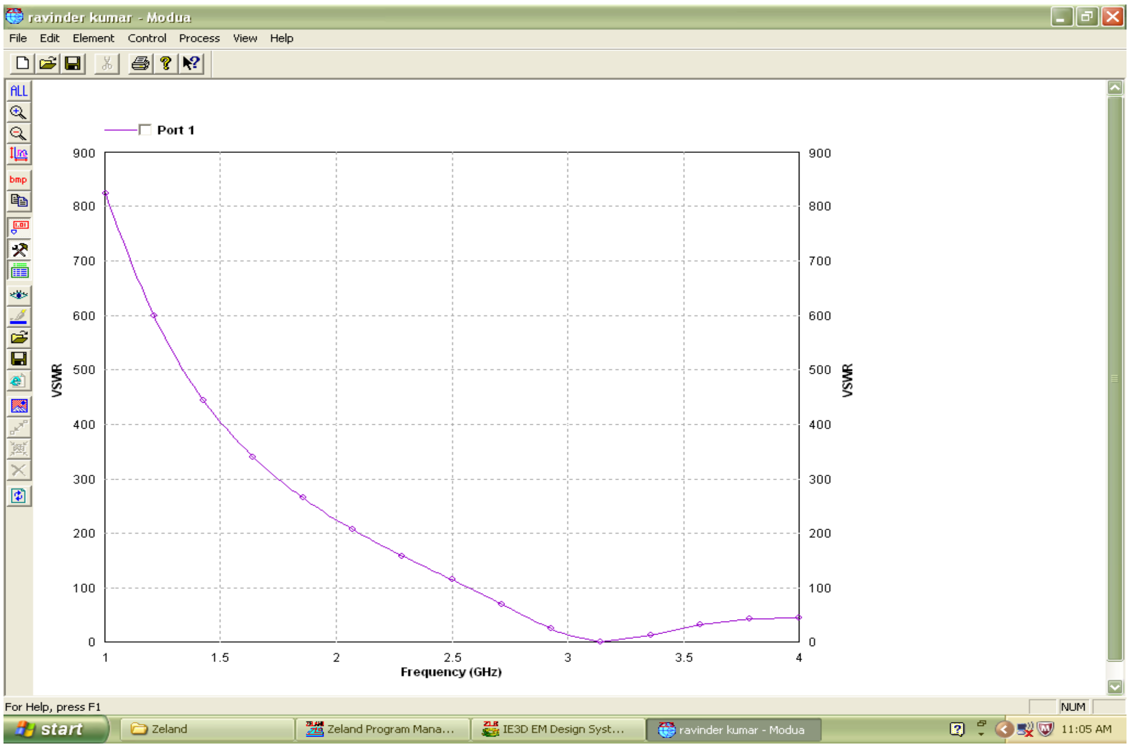


Fig. 5.15 VSWR vs frequency

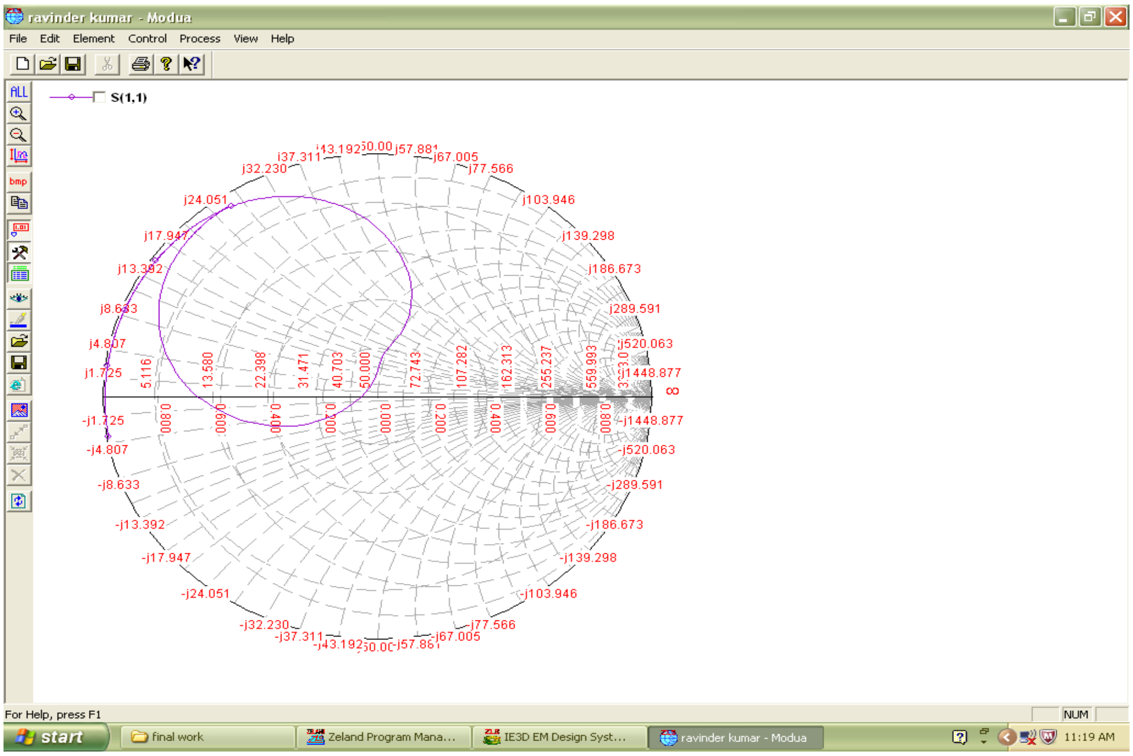
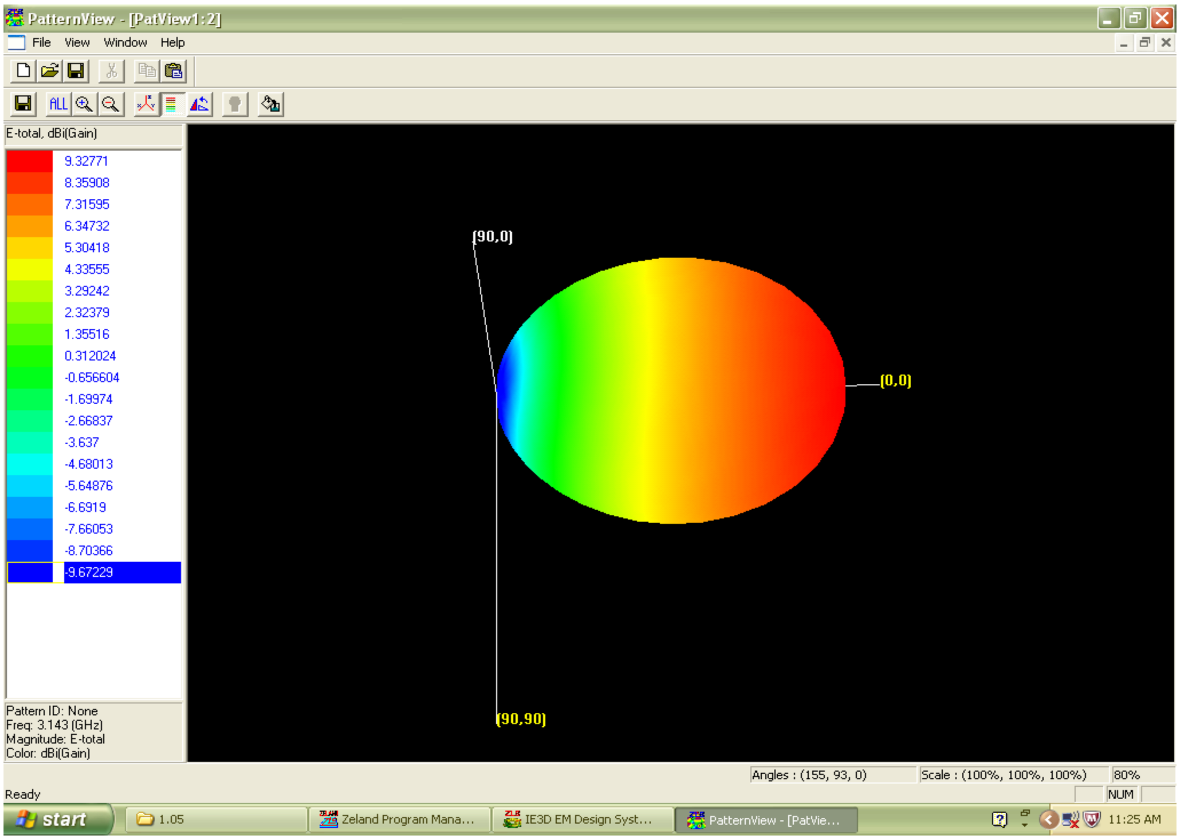


Fig. 5.16 Smith Chart



E-total, dBi(Gain)

9.32771
8.35908
7.31595
6.34732
5.30418
4.33555
3.29242
2.32379
1.35516
0.312024
-0.656604
-1.69974
-2.66837
-3.637
-4.68013
-5.64876
-6.6919
-7.66053
-8.70366
-9.67229

Pattern ID: None
Freq: 3.143 (GHz)
Magnitude: E-total
Color: dBi(Gain)

Angles : (155, 93, 0)
Scale : (100%, 100%, 100%)
80%
Ready
NUM

Fig. 5.17 3D Radiation Pattern

5.5.2 Material- Duroid ; Electrical Permittivity (εr) : 2.2

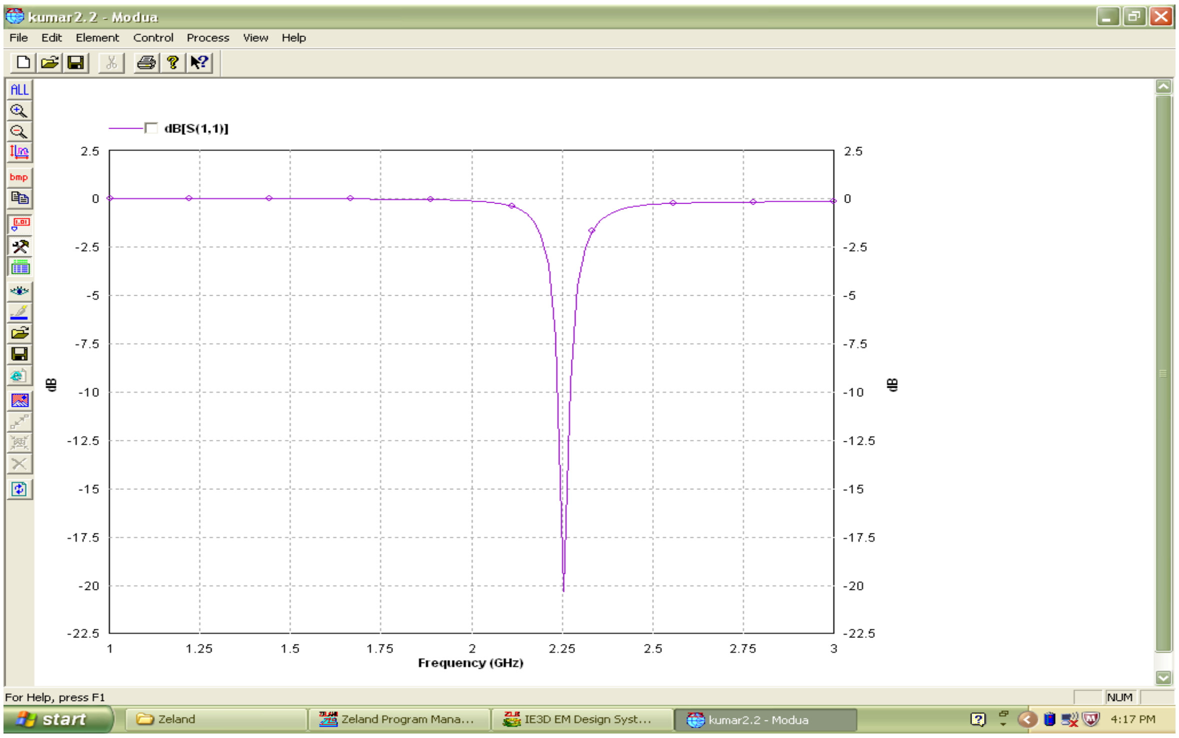


Fig. 5.18 Return Loss vs frequency

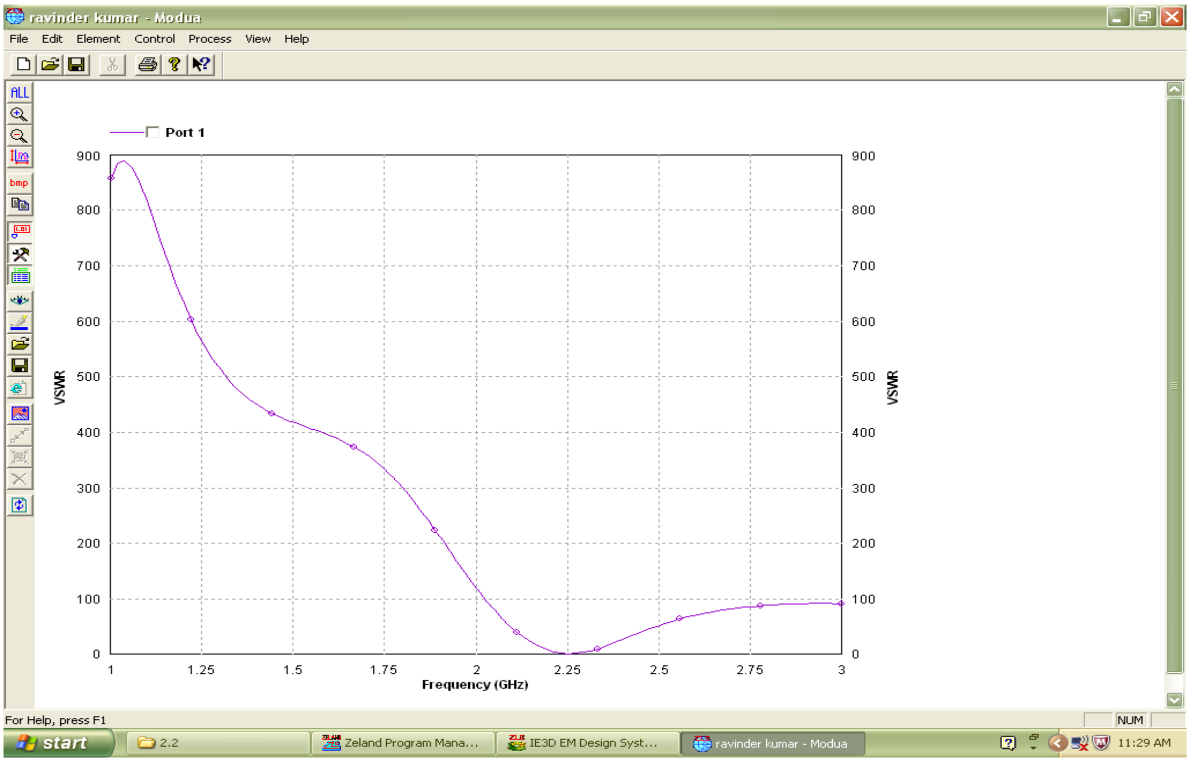


Fig. 5.19 VSWR vs frequency

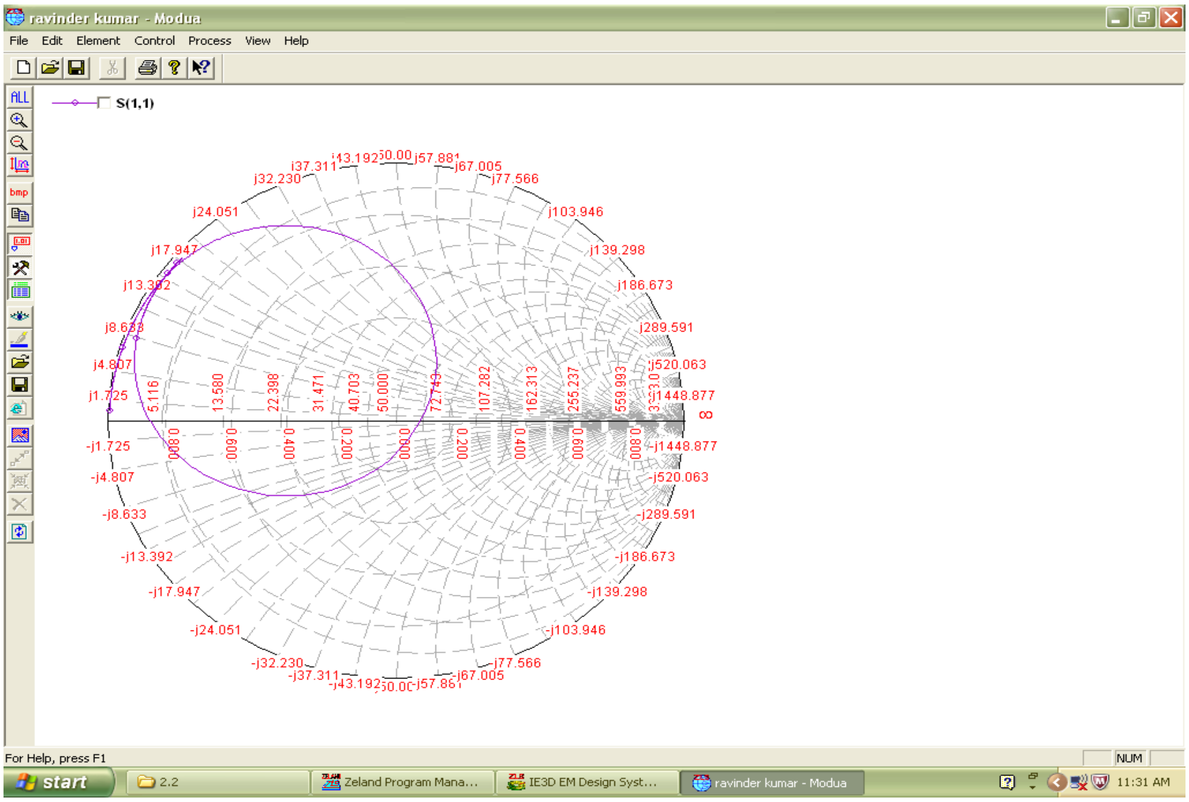
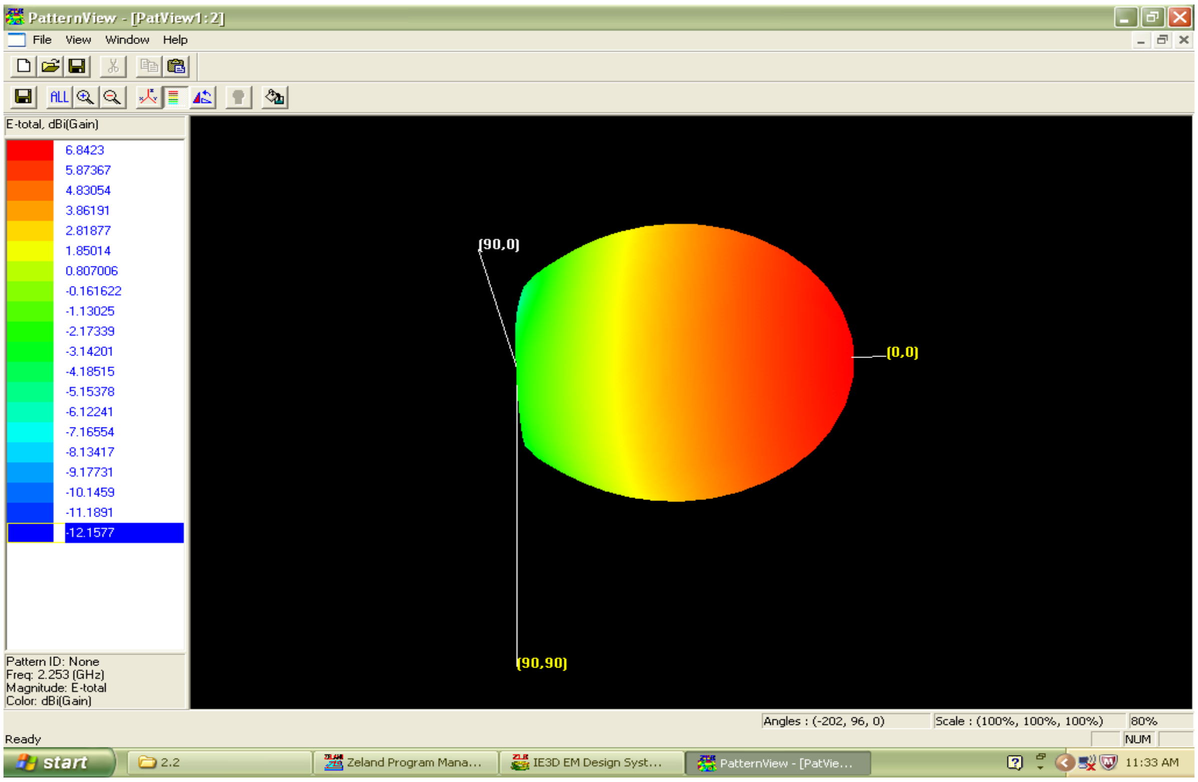


Fig. 5.20 Smith Chart



Pattern ID: None
Freq: 2.253 (GHz)
Magnitude: E-total
Color: dBi(Gain)

Angles : (-202, 96, 0)
Scale : (100%, 100%, 100%)
80%

Fig. 5.21 3D Radiation Pattern

5.5.3 Material- Benzo-cyclo-buten ;   Electrical Permittivity (εr) : 2.6

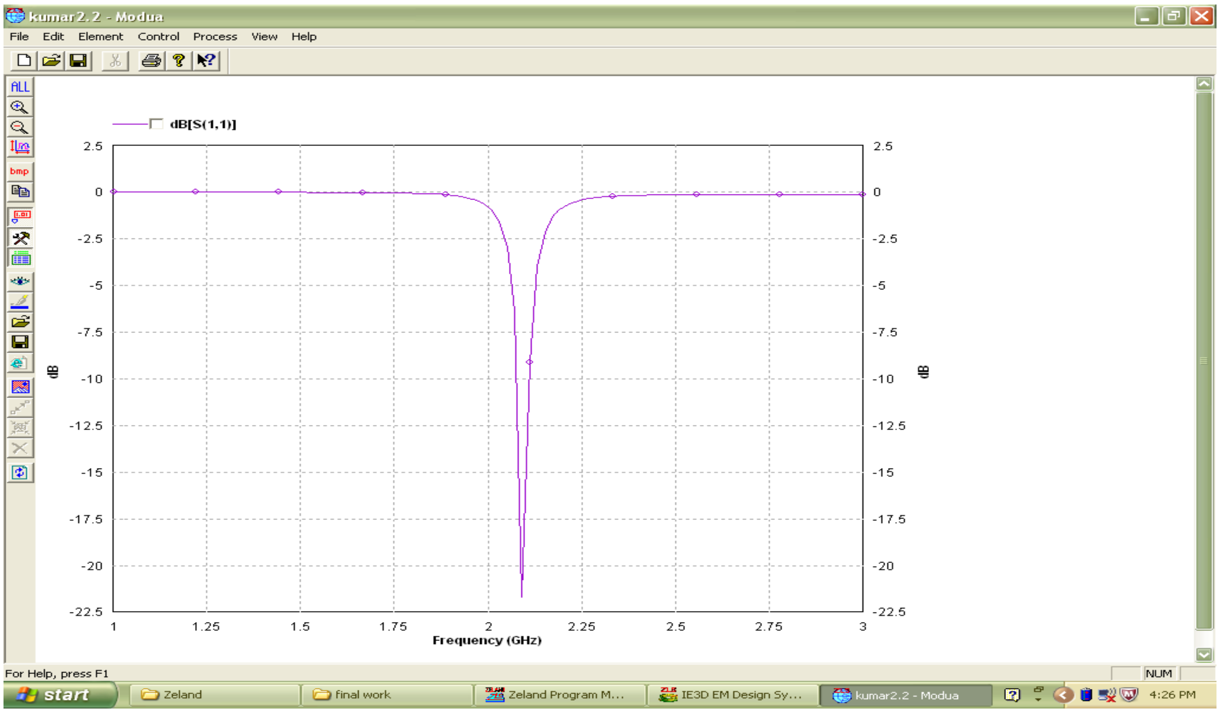


Fig. 5.22 Return Loss vs frequency

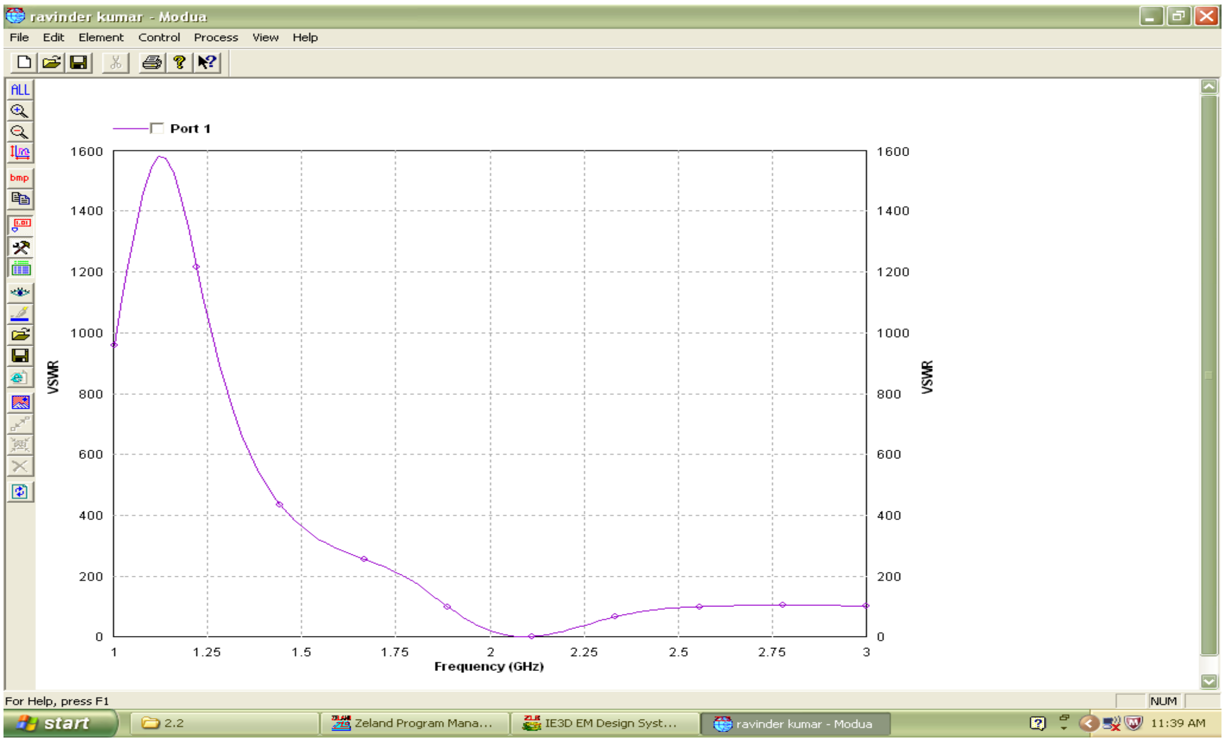


Fig. 5.23 VSWR vs frequency

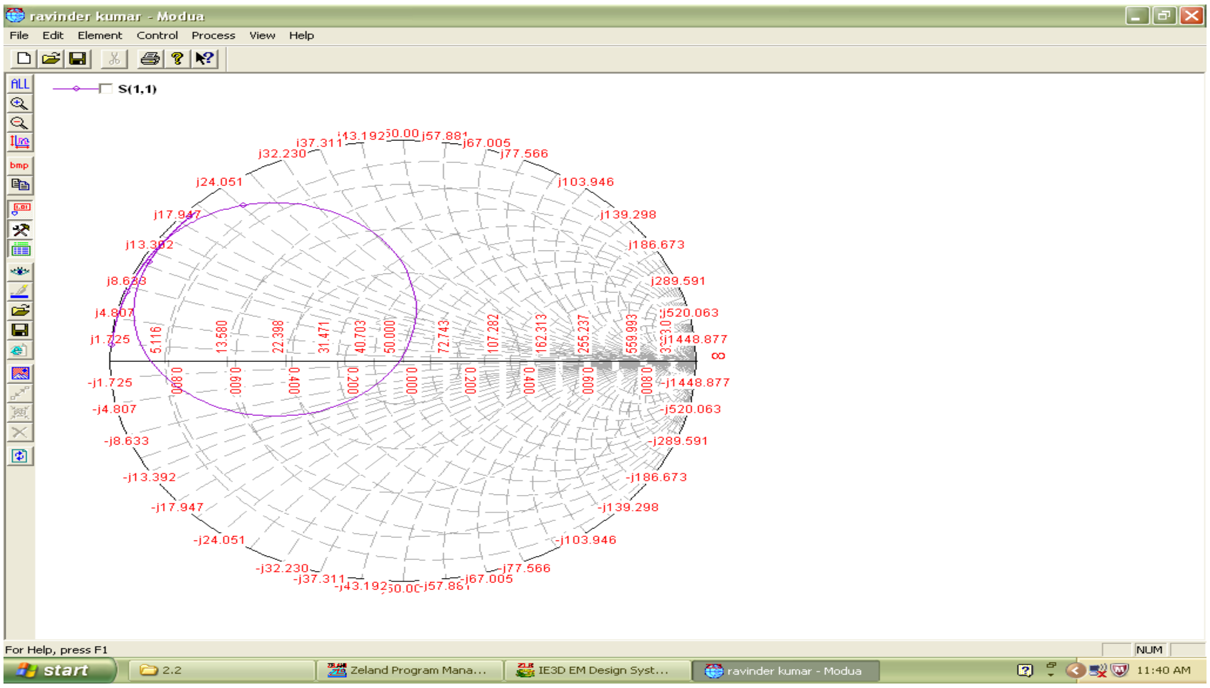
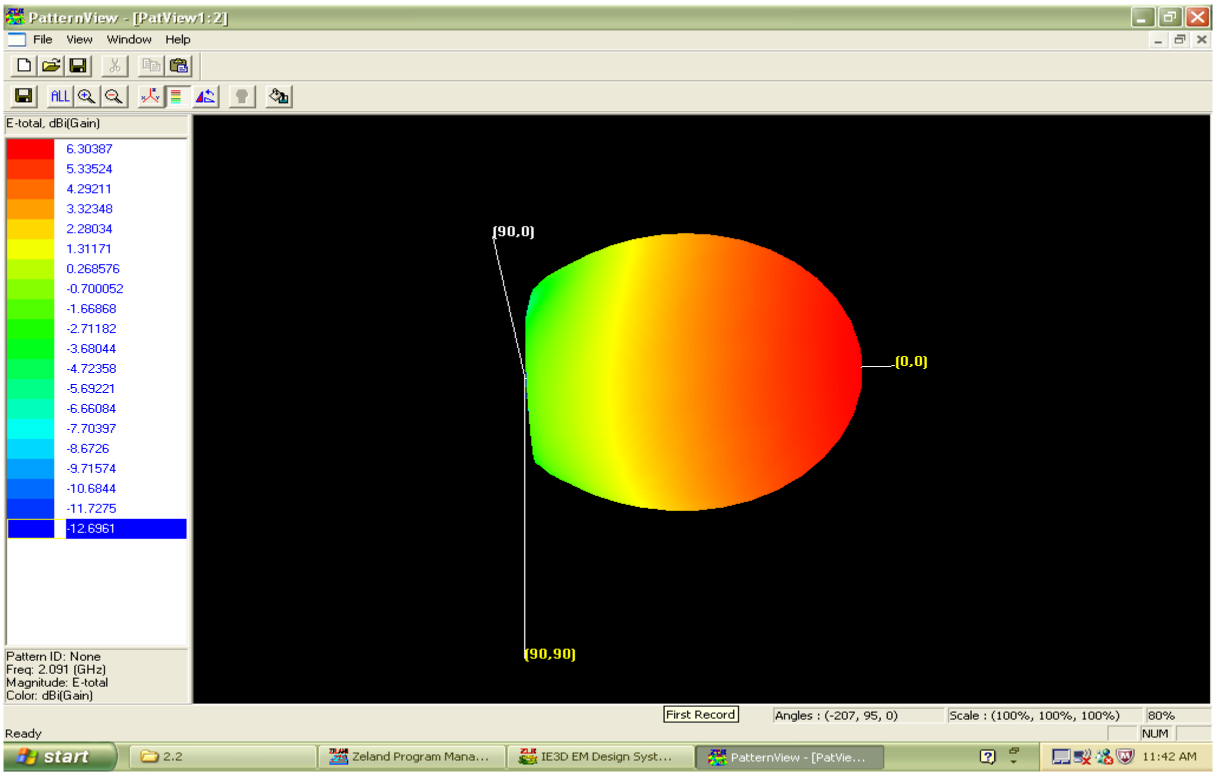


Fig. 5.24 Smith Chart



Pattern ID: None
Freq: 2.091 (GHz)
Magnitude: E-total
Color: dBi(Gain)

Angles : (-207, 95, 0)

Scale : (100%, 100%, 100%)

80%

Ready

Fig. 5.25 3D Radiation Pattern

5.5.4 Material- Roger 4350 ; Electrical Permittivity (εr) : 3.48

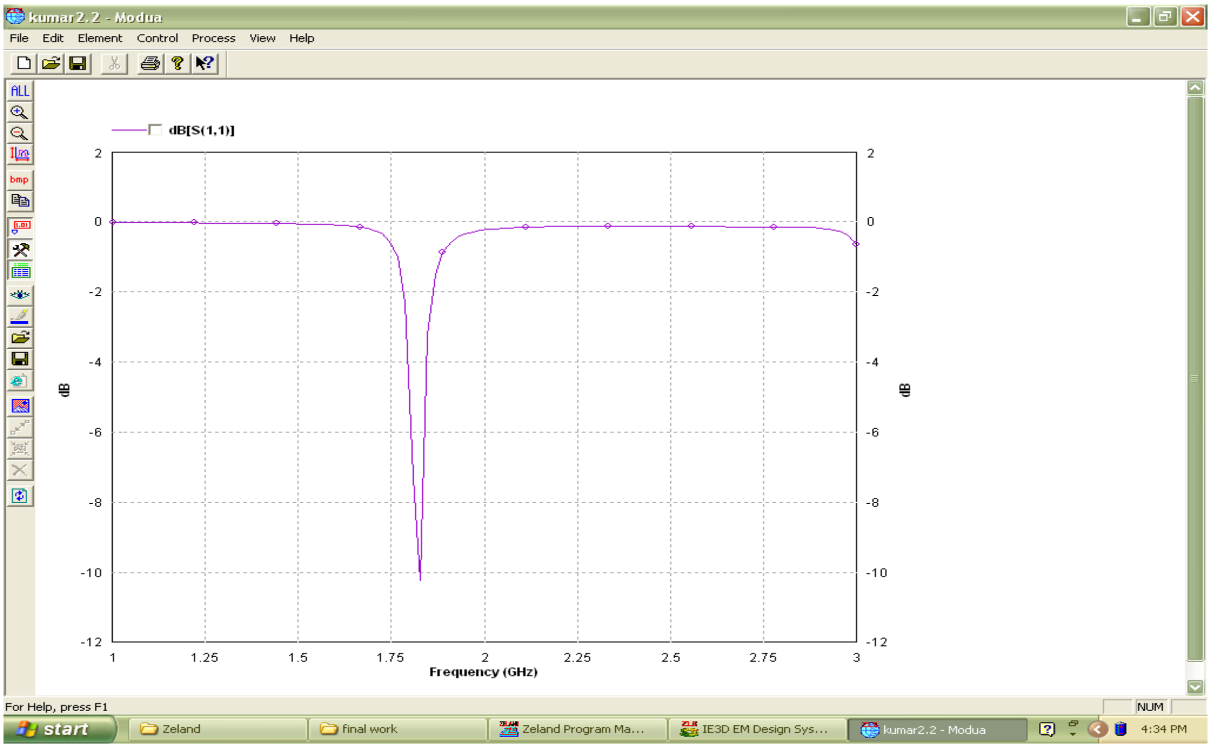


Fig. 5.26 Return Loss vs frequency

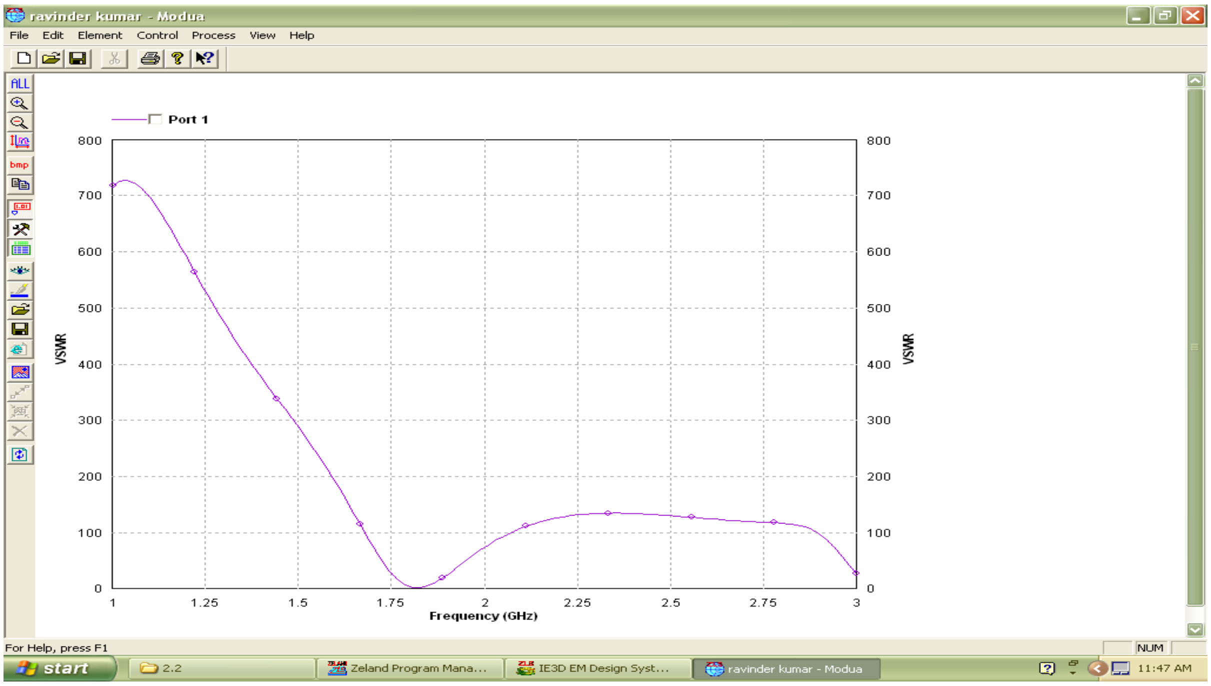
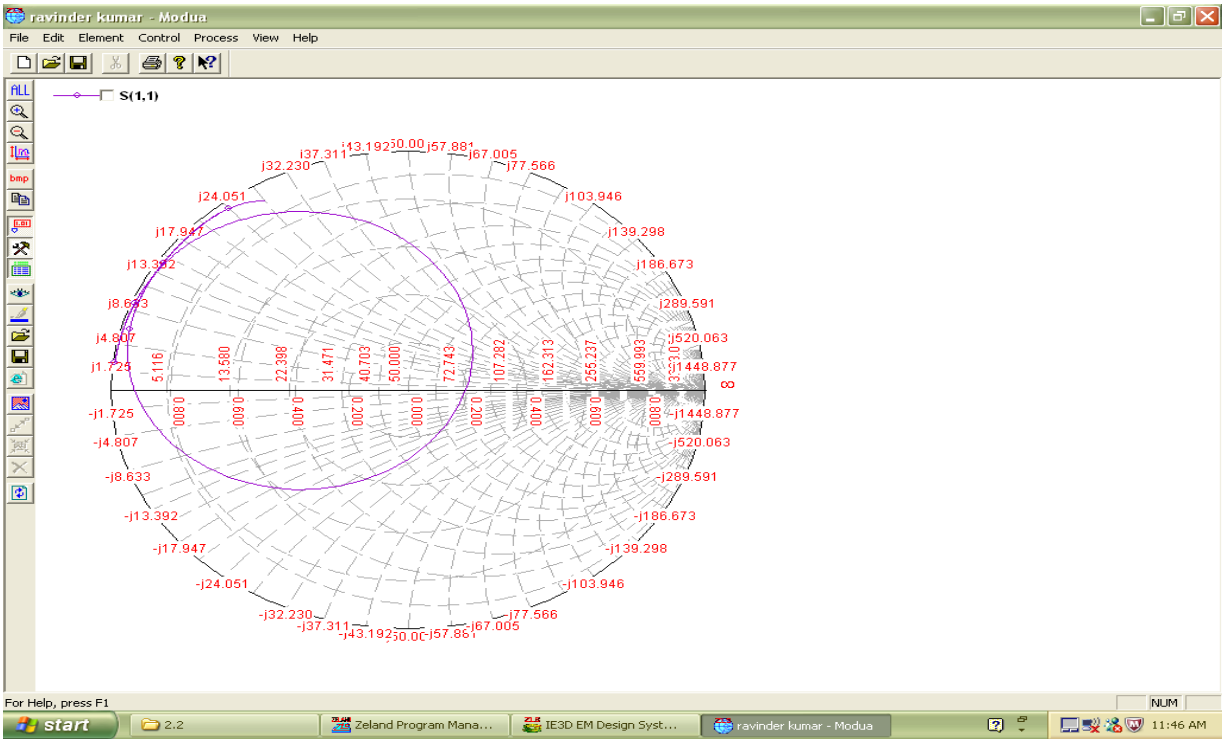
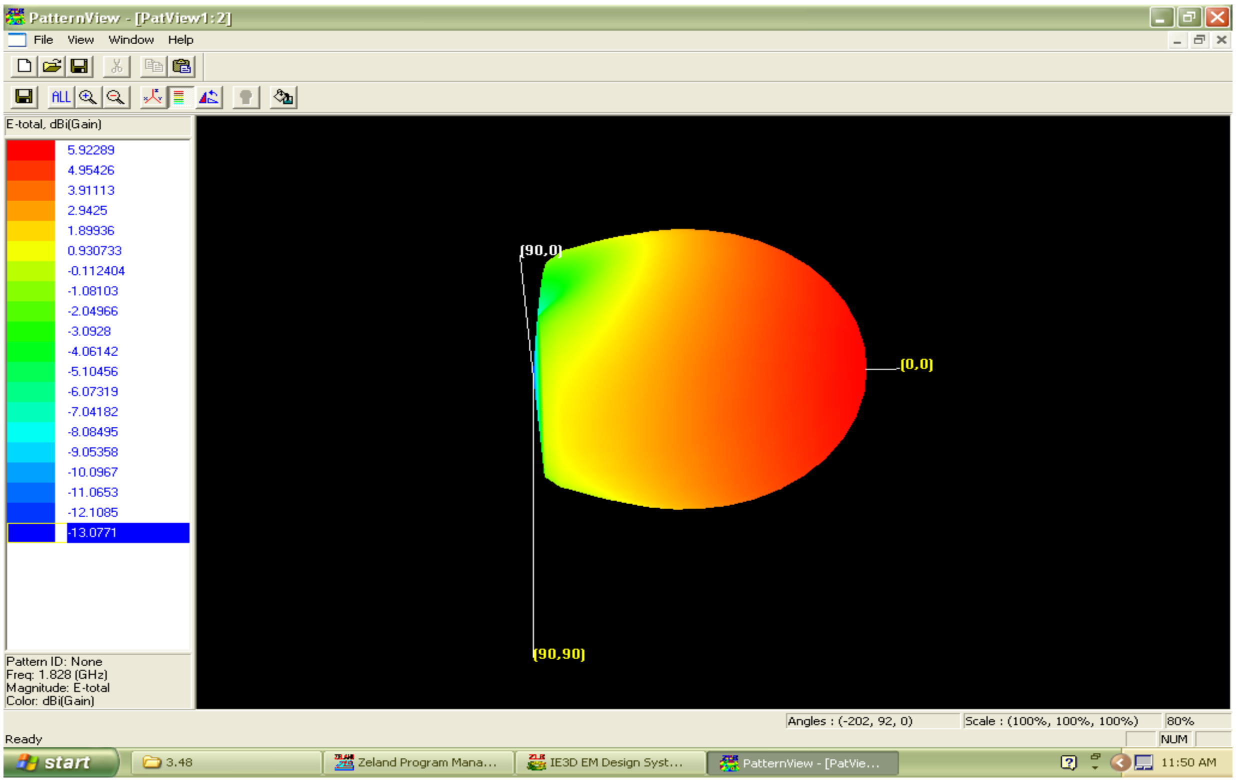


Fig. 5.27 VSWR vs frequency



For Help, press F1

Fig. 5.28 Smith Chart



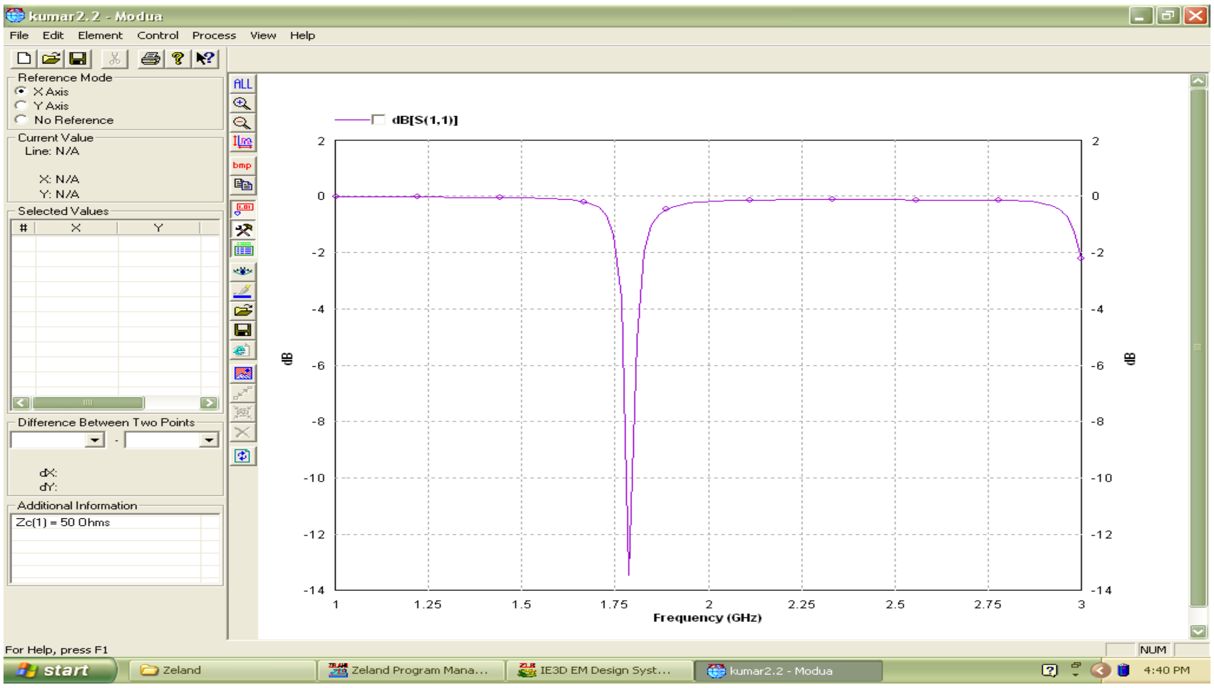
Pattern ID: None
Freq: 1.828 (GHz)
Magnitude: E-total
Color: dBi(Gain)

Angles : (-202, 92, 0)
Scale : (100%, 100%, 100%)
80%

Ready

Fig. 5.29 3D Radiation Pattern

5.5.5 Material- Epoxy ; Electrical Permittivity (εr) : 3.6



Reference Mode
● X Axis
○ Y Axis
○ No Reference

Current Value
Line: N/A
X: N/A
Y: N/A

Selected Values

#	X	Y

Difference Between Two Points
dX:
dY:

Additional Information
Zc(1) = 50 Ohms

Fig. 5.30 Return Loss vs frequency

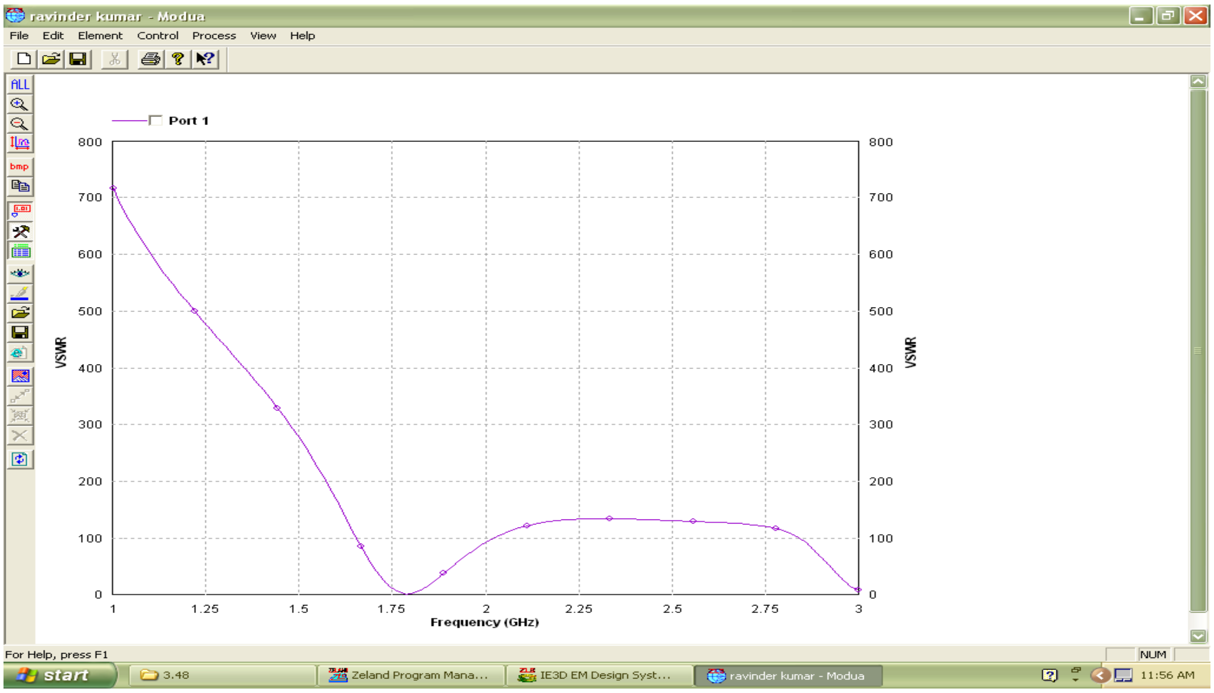


Fig. 5.31 VSWR vs frequency

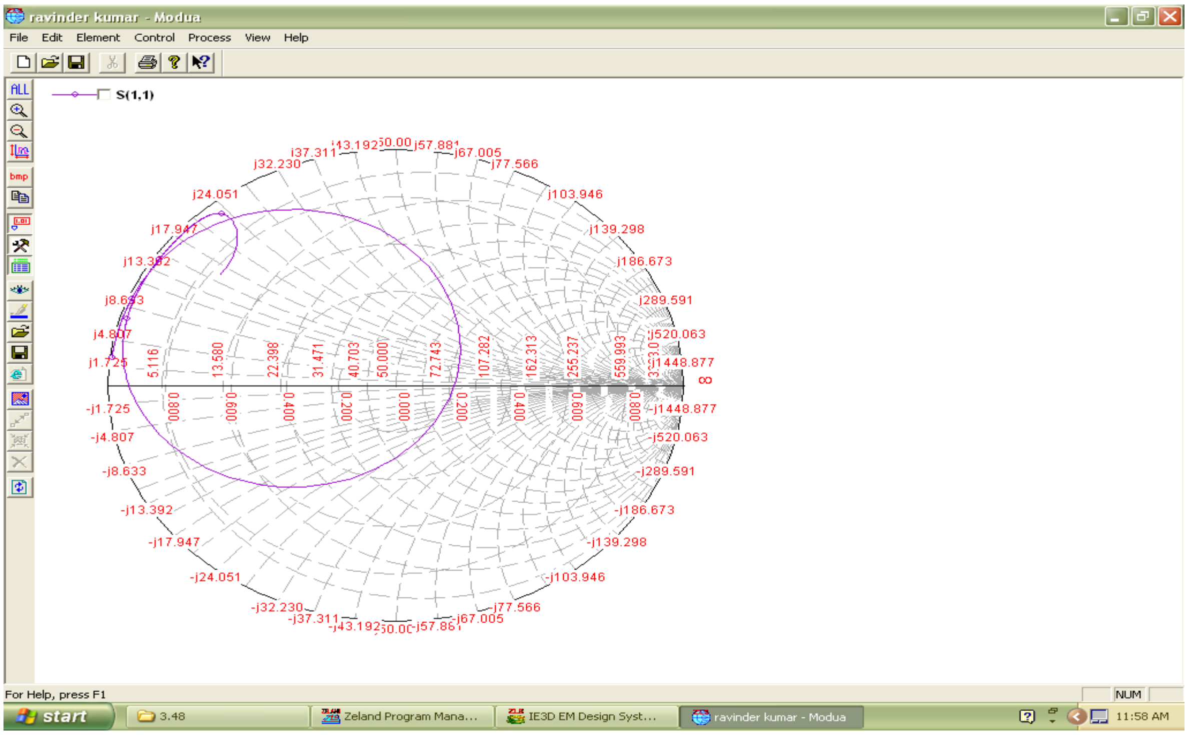
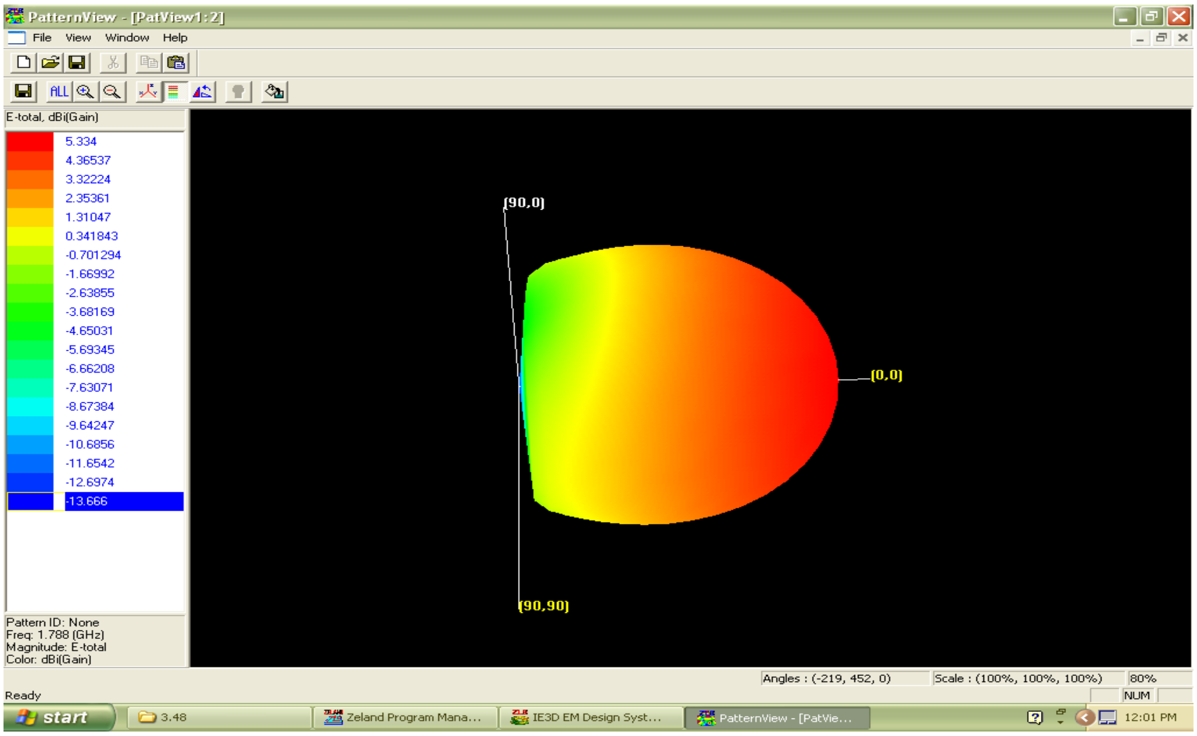


Fig. 5.32 Smith Chart



Pattern ID: None
Freq: 1.788 (GHz)
Magnitude: E-total
Color: dBi(Gain)

Angles : (-219, 452, 0)
Scale : (100%, 100%, 100%)
80%

Fig. 5.33 3D Radiation Pattern

5.5.6 Material- FR4 ; Electrical Permittivity (εr) : 4.4

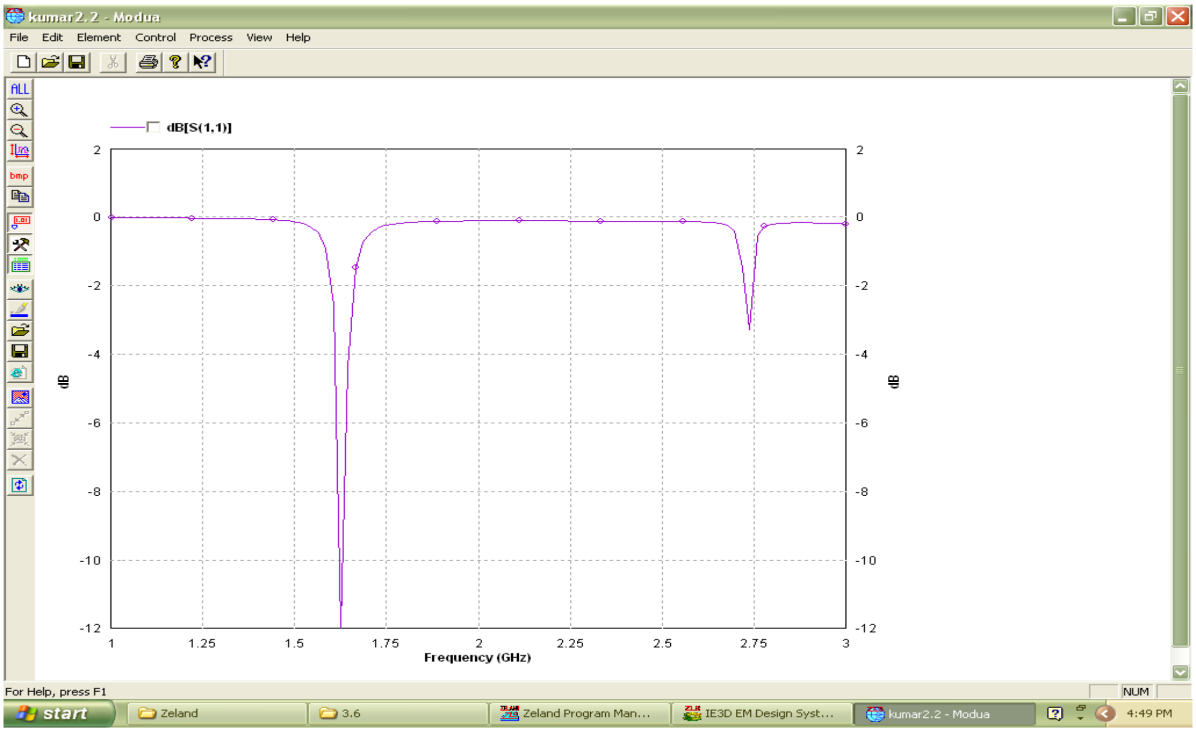


Fig. 5.34 Return Loss vs frequency

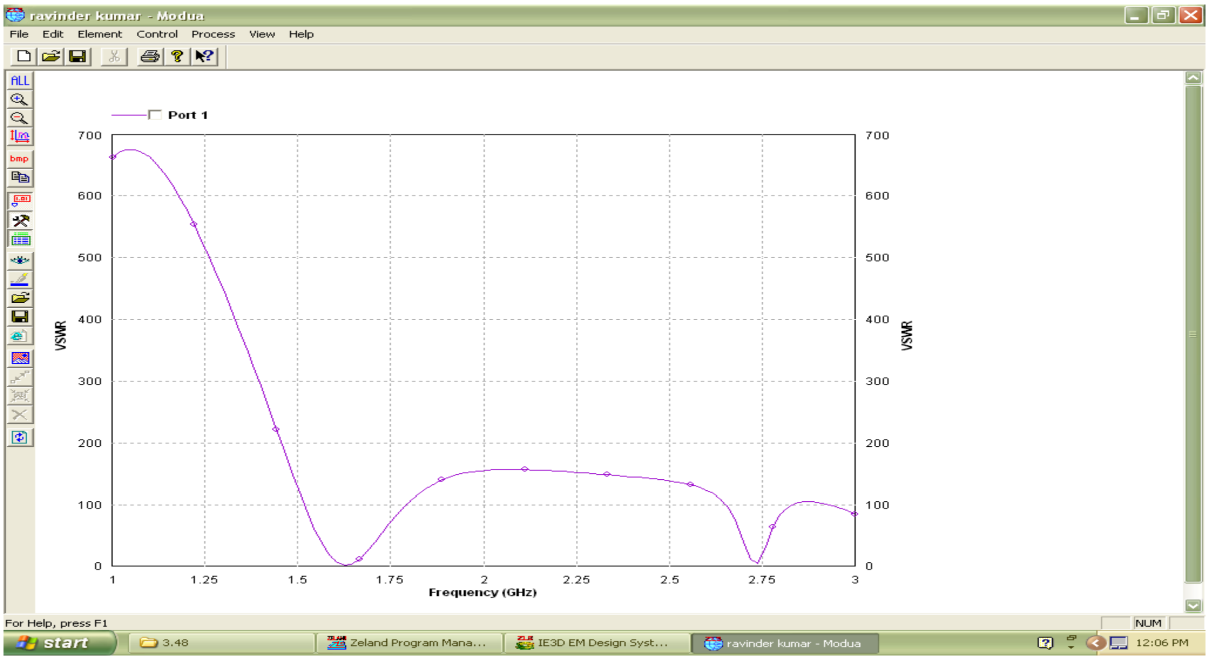
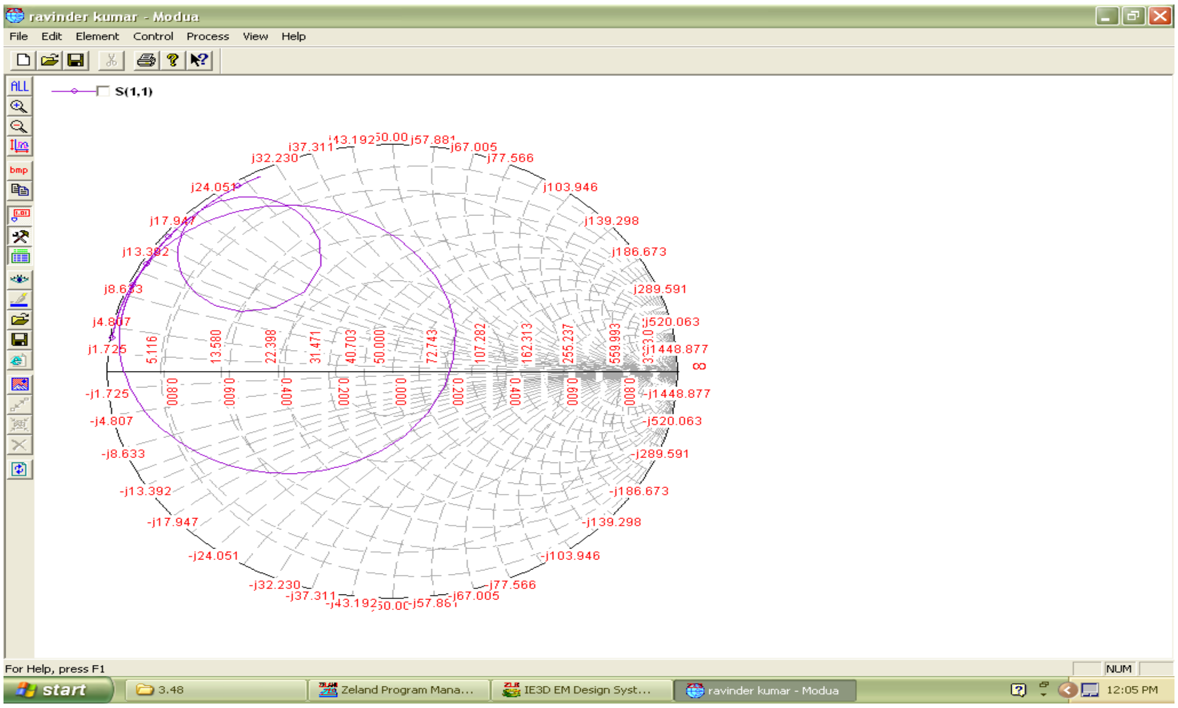
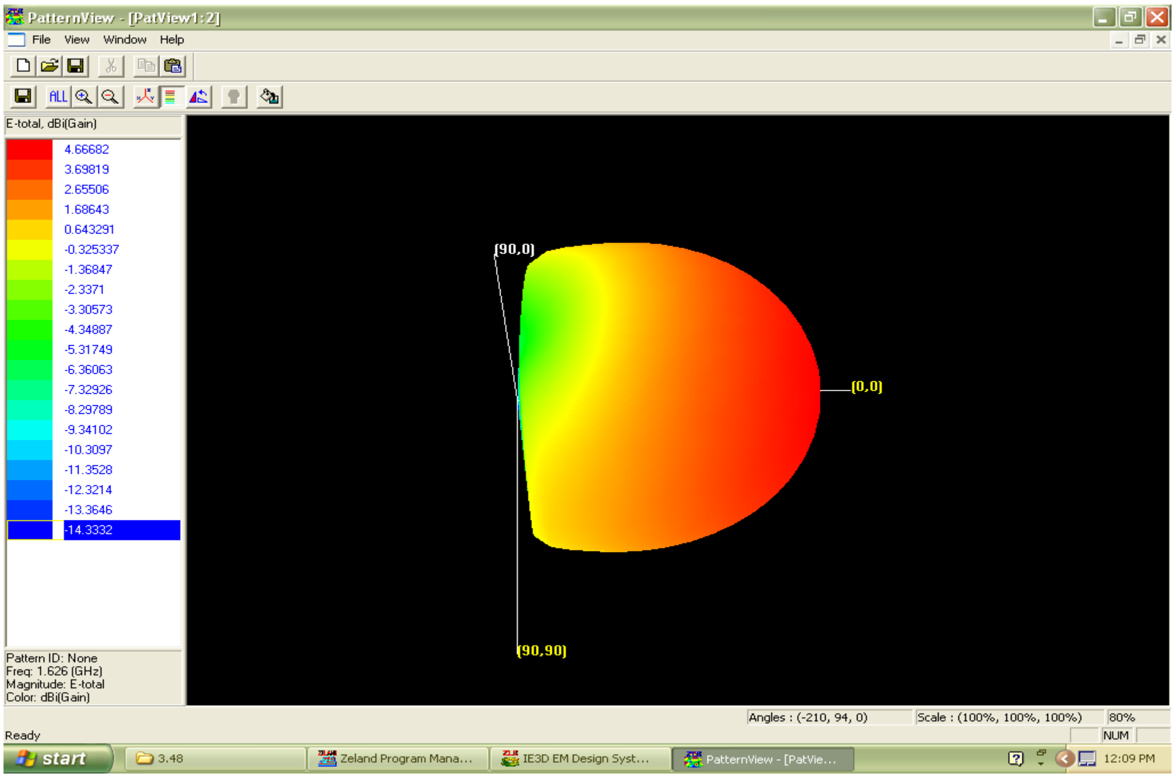


Fig. 5.35 VSWR vs frequency



For Help, press F1

Fig. 5.36 Smith Chart



Pattern ID: None
Freq: 1.626 (GHz)
Magnitude: E-total
Color: dBi(Gain)

Angles : (-210, 94, 0)
Scale : (100%, 100%, 100%)
80%

Ready

Fig. 5.37 3D Radiation Pattern

5.5.7 Material- Glass ; Electrical Permittivity (εr) : 5.5

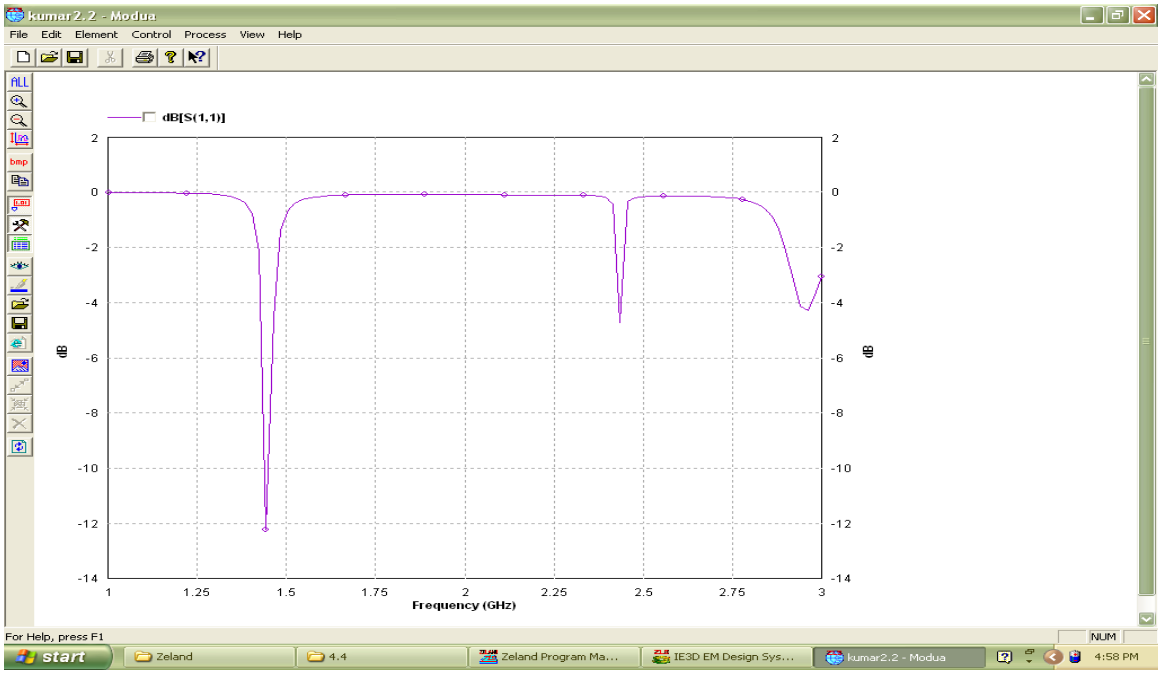


Fig. 5.38 Return Loss vs frequency

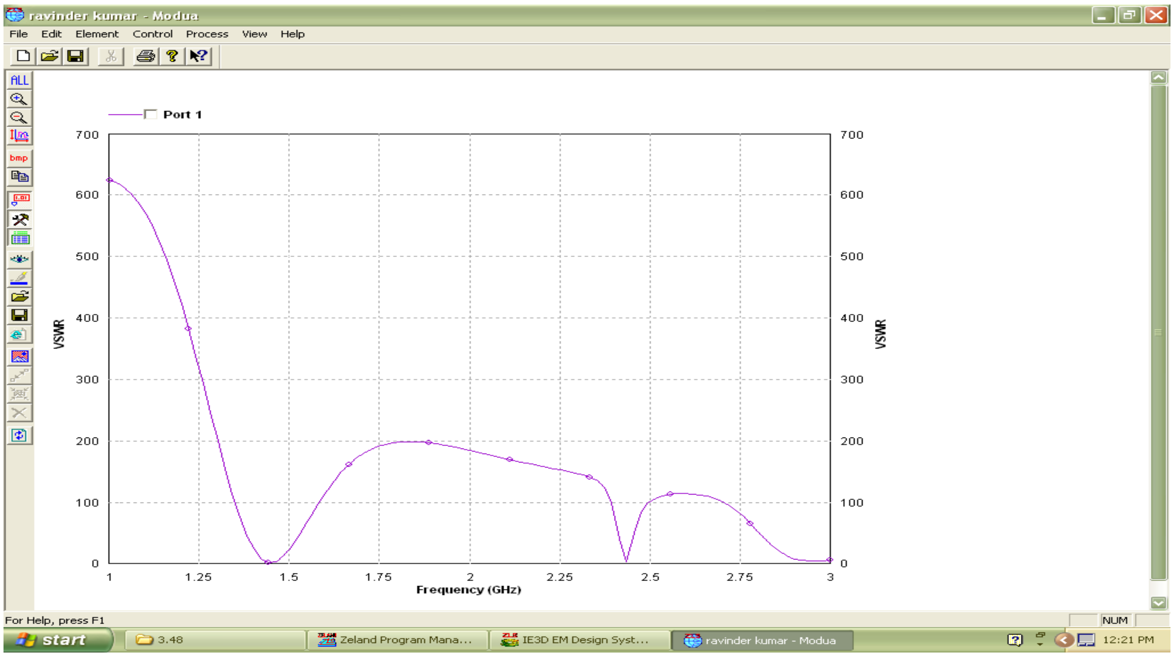


Fig. 5.39 VSWR vs frequency

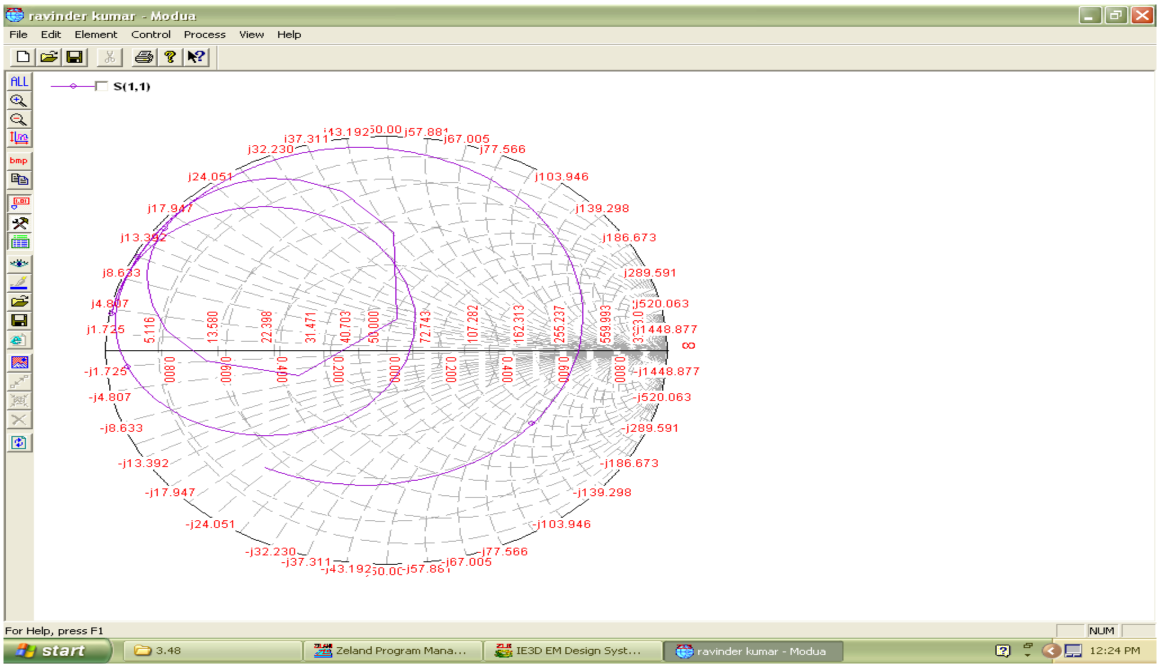
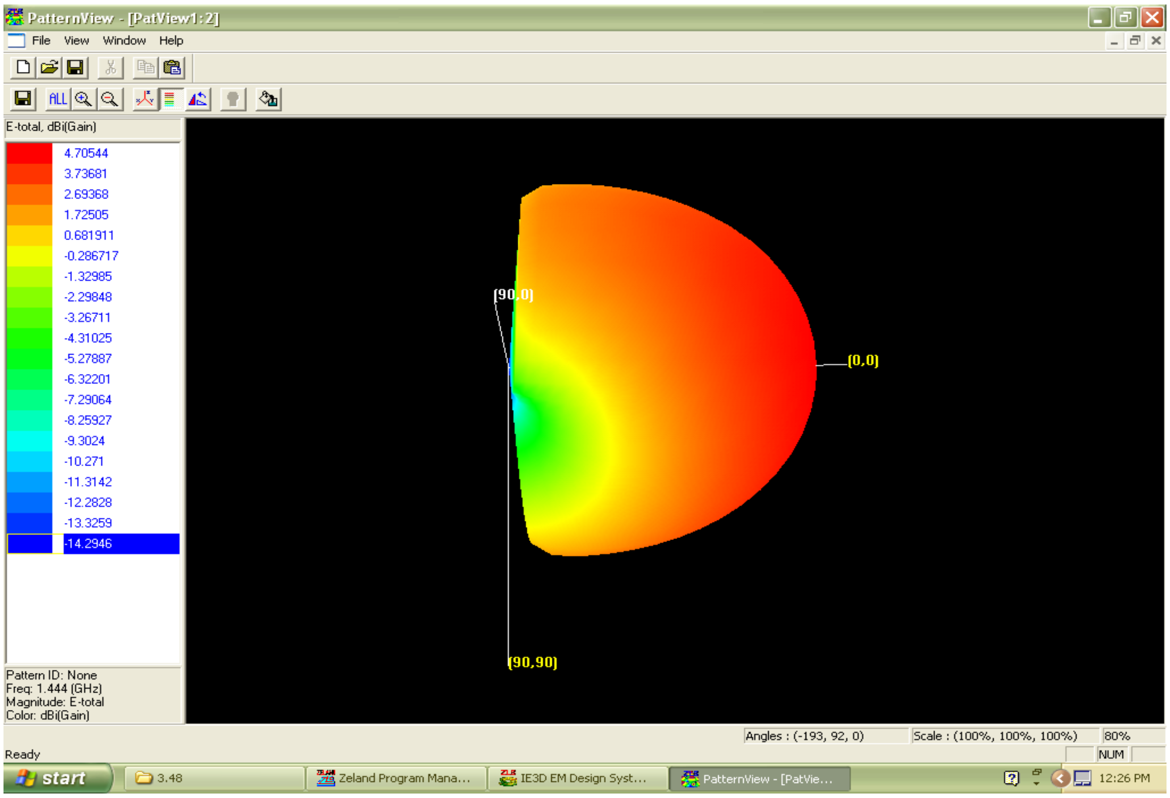


Fig. 5.40 Smith Chart

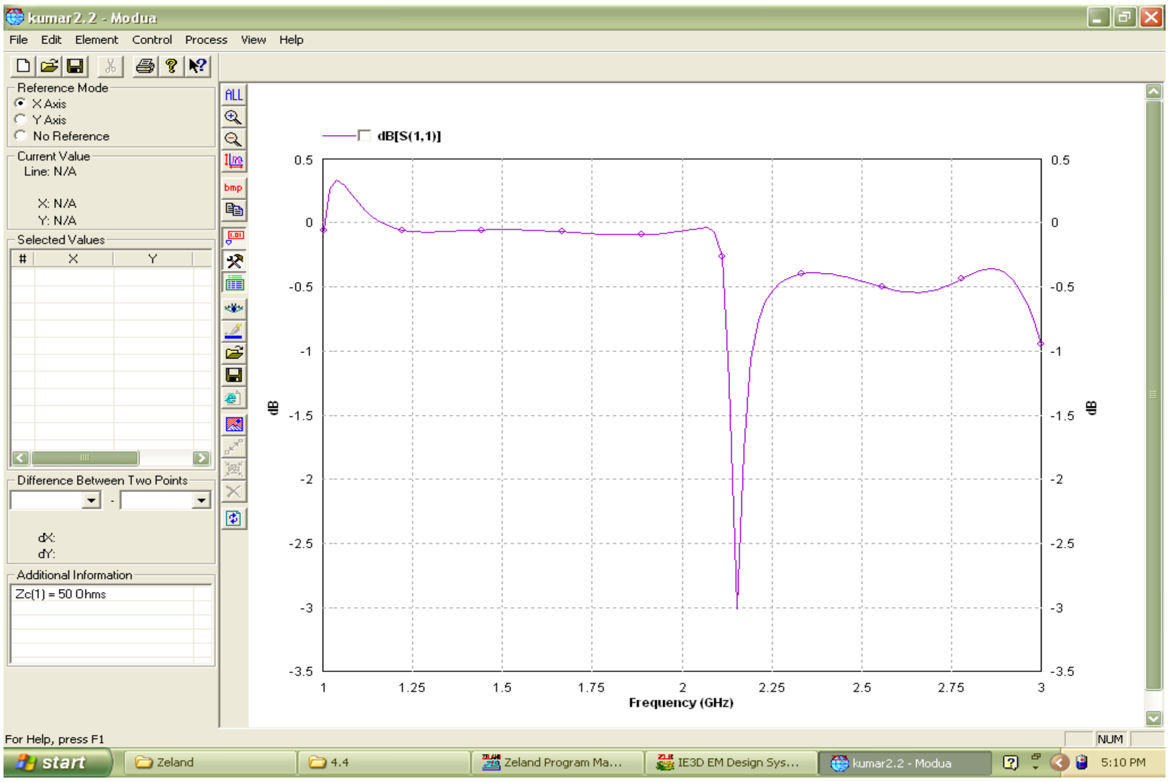


Pattern ID: None
Freq: 1.444 (GHz)
Magnitude: E-total
Color: dBi(Gain)

Angles : (-193, 92, 0)
Scale : (100%, 100%, 100%)
80%

Fig. 5.41 3D Radiation Pattern

5.5.8 Material- Duroid 6010; Electrical Permittivity (εr) : 10.2



Reference Mode
● X Axis
○ Y Axis
○ No Reference

Current Value
Line: N/A
X: N/A
Y: N/A

Difference Between Two Points
dX:
dY:

Additional Information
Zc(1) = 50 Ohms

Fig. 5.42 Return Loss vs frequency

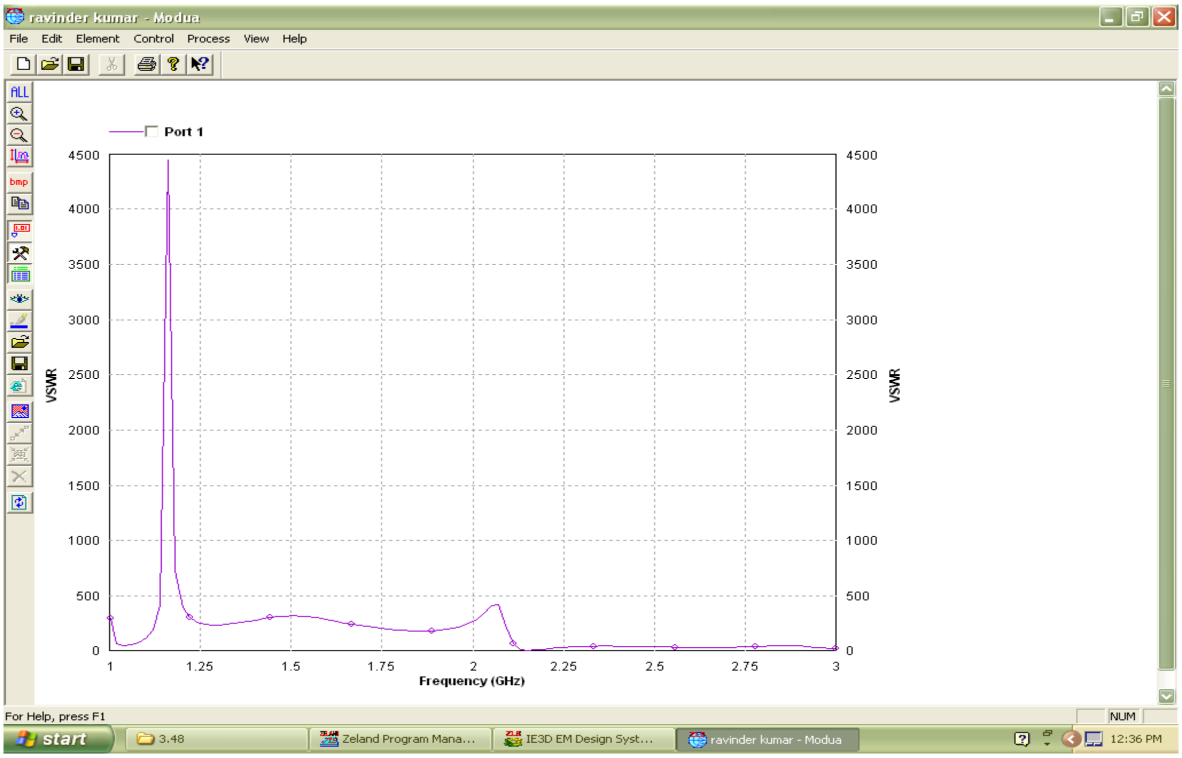
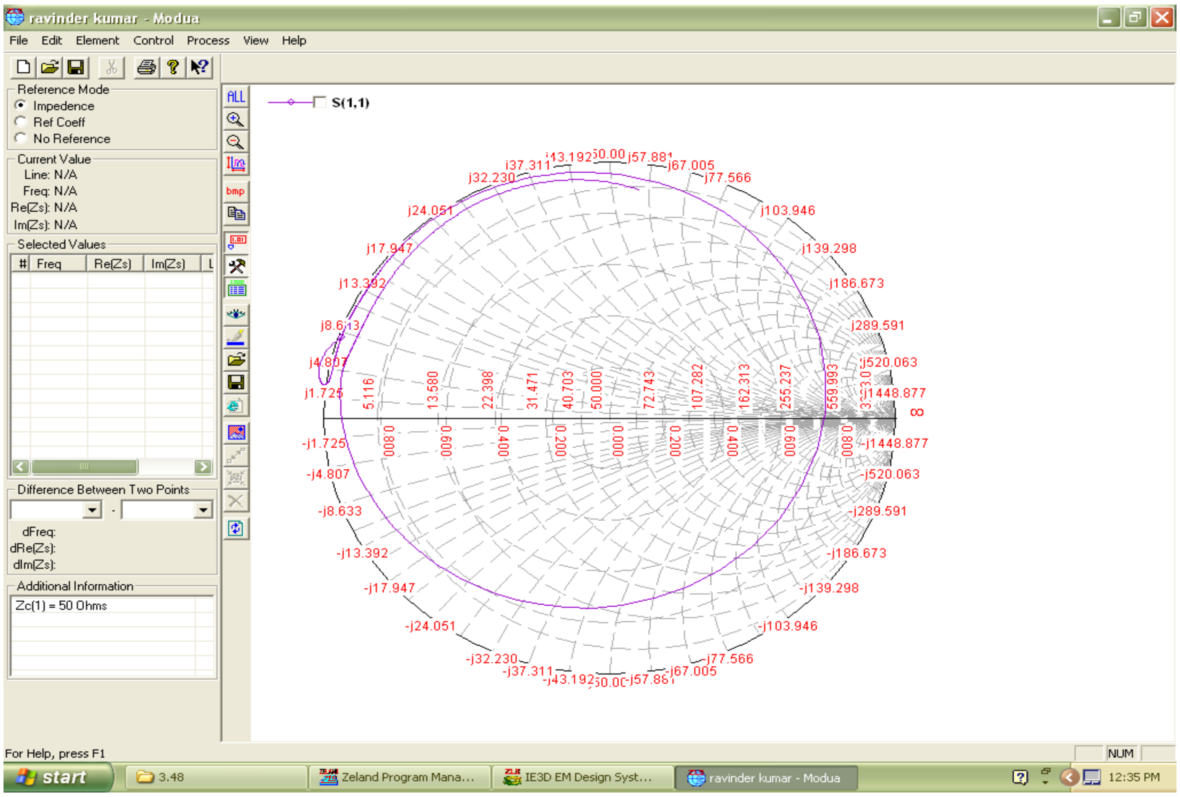


Fig. 5.43 VSWR vs frequency



Reference Mode
● Impedence
○ Ref Coeff
○ No Reference

Current Value
Line: N/A
Freq: N/A
Re(Zs): N/A
Im(Zs): N/A

Selected Values

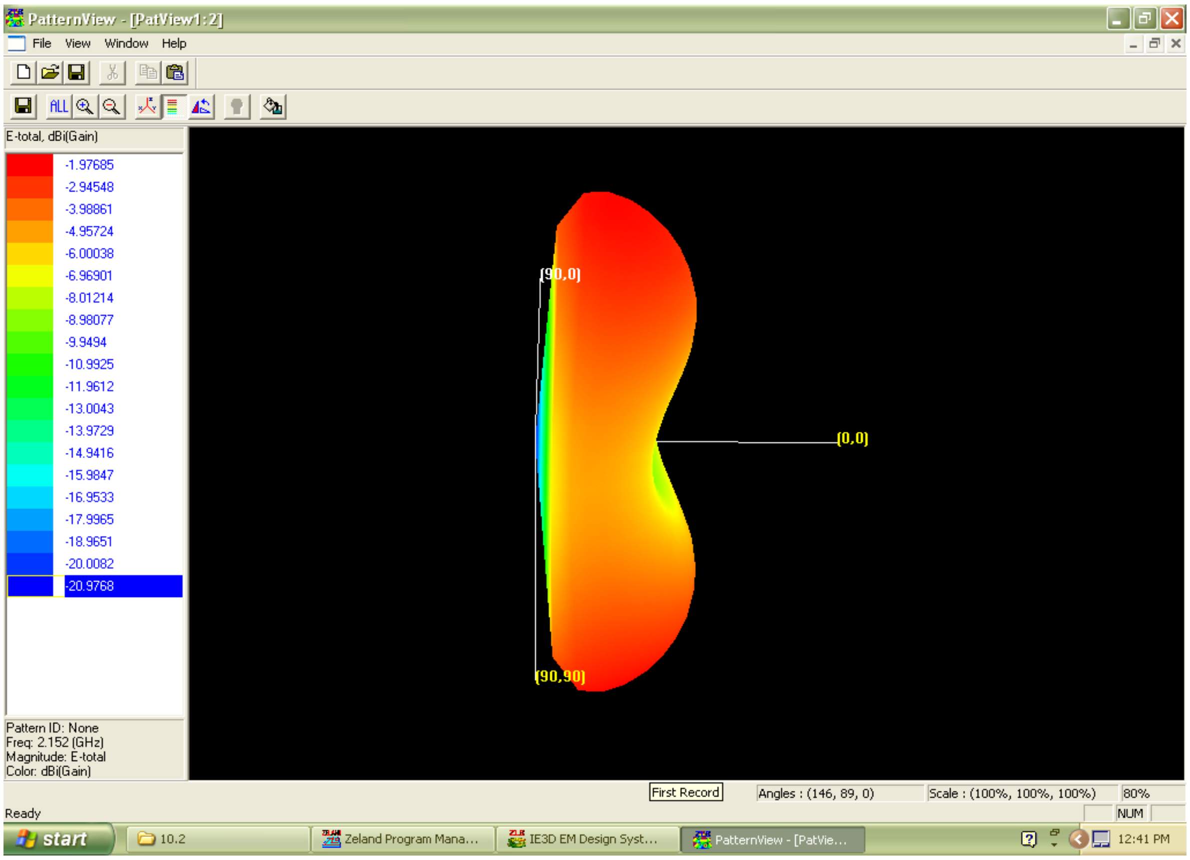
#	Freq	Re(Zs)	Im(Zs)

Difference Between Two Points
dFreq:
dRe(Zs):
dIm(Zs):

Additional Information
Zc(1) = 50 Ohms

For Help, press F1

Fig. 5.44 Smith Chart



E-total, dBi(Gain)

-1.97685
-2.94548
-3.98861
-4.95724
-6.00038
-6.96901
-8.01214
-8.98077
-9.9494
-10.9925
-11.9612
-13.0043
-13.9729
-14.9416
-15.9847
-16.9533
-17.9965
-18.9651
-20.0082
-20.9768

Pattern ID: None
Freq: 2.152 (GHz)
Magnitude: E-total
Color: dBi(Gain)

Angles : (146, 89, 0)
Scale : (100%, 100%, 100%)
80%
Ready
NUM

Fig. 5.45 3D Radiation Pattern

5.5.9 COMPARISION OF SIMULATION RESULTS

S.NO	Material	Permitti -vity (εr)	Return Loss (S11)	Radiation Efficiency	Antenna Efficiency	Gain	Directivity	Resonant frequency (GHz)	VSWR
1	Foam	1.05	-15.11	97.1342	94.1646	9.32771	9.58884	3.143	1.426
2	Duroid	2.2	-20.35	89.6509	86.2781	6.84867	7.48366	2.253	1.213
3	Benzo Cyclo buten	2.6	-21.72	85.6381	82.6534	6.30348	7.13087	2.091	1.179
4	Roger 4350	3.48	-10.22	86.1252	85.1188	5.91929	6.61903	1.828	1.902
5	Epoxy	3.6	-13.47	85.5791	75.4831	5.33436	6.55586	1.788	1.538
6	FR4	4.4	-11.99	83.7916	69.0712	4.6715	6.27854	1.626	1.665
7	Glass	5.5	-12.22	80.2515	73.9882	4.70352	6.01193	1.444	1.646
8	Duroid 6010	10.2	-3.011	77.5092	16.6698	-1.9807	5.80064	2.152	5.841

5.10 RESULT

The Study has been conducted to observe the changes in different parameters of Microstrip antenna with the usage of different types of Substrate.By observing the result, the return loss sometime increases and decreases with substrate permittivity. we get best return loss from benzocyclobuten dielectric. The worst return loss was given by duroid 6010. it is given only -3.011db return loss which is very less than -10db. The resonant frequency slightly decreases with increase in electrical permittivity of the substrates used except duroid 6010.

By observing result ,we can say that the radiation efficiency, continuous decrease with increase material permittivity.Antenna efficiency is also decrease with increase permittivity. In this case the best radiation efficiency and antenna efficiency given by form material but their return loss is not so good and their resonant frequency is 3.143GHz. Gain and Directivity is slightly decrease with increase electrical permittivity as shown in graph. VSWR is sometime increase and decrease with permittivity. The best VSWR is given by benzocyclobuten dielectric.

The overall result is that, the benzocyclobuten dielectric is best in comparison of other dielectric because it has good result in all direction or in all parameters. It is much more cost effective than others.so that we design a Cross-Shaped Slot Microstrip Antenna by benzocyclobuten dielectric with electrical permittivity 2.6.

CHAPTER-6

DESIGN OF CROSS-SHAPED COMPACT MICROSTRIP ANTENNA

A microstrip antennas generally have a conducting patch printed on a substrate, and have the attractive features of low profile as light weight, easy fabrication, and conformability to mounting hosts [12]. However, microstrip antennas inherently have a narrow bandwidth, and bandwidth enhancement is usually demanded for practical applications. But now a days the applications of antennas in mobile communication systems usually require smaller size in order to meet the miniaturization requirements of mobile units. Thus, size reduction and bandwidth enhancement are becoming major design considerations for practical applications of microstrip antennas. So this reason, studies of achieve compact microstrip antennas have greatly increased. Much significant progress in the design of compact microstrip antennas with broadband, dual-frequency, dualpolarized, circularly polarized, and gain-enhanced operations have been reported over the past several years. This thesis design a cross-shaped compact microstrip antenna.

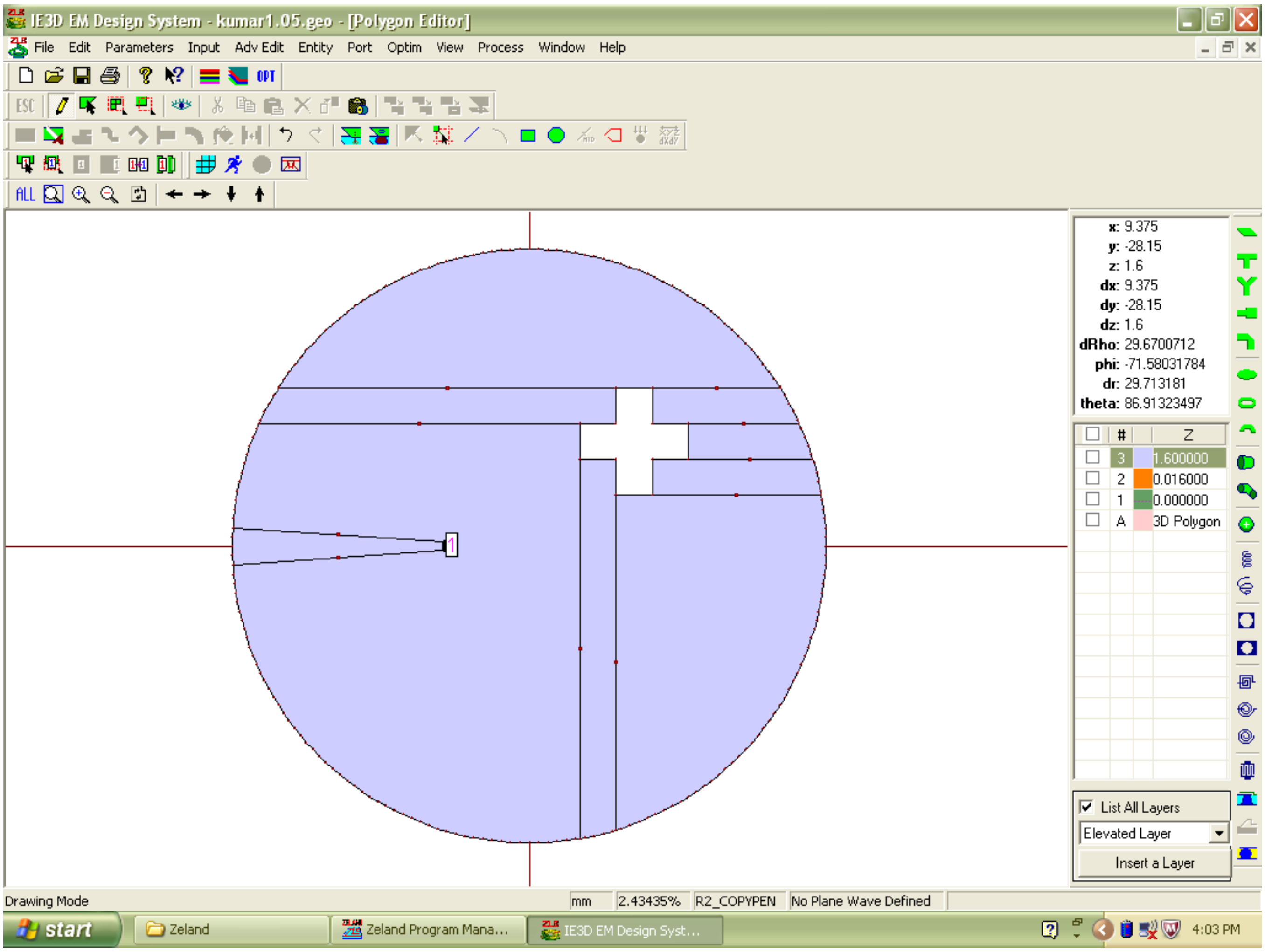
6.1 Design of Cross-Shaped Compact Microstrip Antenn.

A Compact Cross Shaped Circular Microstrip Antenna (CCSCMA) is simulated and designed. The antenna consists of dielectric constant (ε*r)* which value is 2.6 mm and thickness is 1.6 mm . A cross Shaped patch cut in first quadrent of microstrip antenna. Two rectangular patches crosses each other and their dimension is 9 mm x 3 mm have been mounted over the substrate to form a Cross Shaped slot . The antenna is excited by a coaxial feed of diameter 0.5 mm given on the X-axis at x= -6.8 & y= 0. The main advantage of using Cross-Shaped patch that is it increases the antenna parameters like antenna efficiency, Radiation efficiency, Bandwidth, gain, directivity etc.

Given specifications were,

1. Dielectric constant (εr) = 2.6
2. Frequency (fr) = 2.091 GHz.
3. Height or thickness (h)= 1.6 mm
4. Velocity of light (c) = 3×10^8 ms-1 .
5.Radius of circle (r) =24.8 mm
7. Cross-shaped slot dimensions = a) one rectangle 3mm × 9 mm.

b) Second rectangle 9mm × 3mm



x: 9.375
y: -28.15
z: 1.6
dx: 9.375
dy: -28.15
dz: 1.6
dRho: 29.6700712
phi: -71.58031784
dr: 29.713181
theta: 86.91323497

☐	#	Z
☐	3	1.600000
☐	2	0.016000
☐	1	0.000000
☐	A	3D Polygon

☑ List All Layers

Drawing Mode | mm | 2.43435% | R2_COPYPEN | No Plane Wave Defined

Fig.6.1 Cross-slot antenna

6.2 Microstrip Cross-Shaped Antenna (Illustrations)

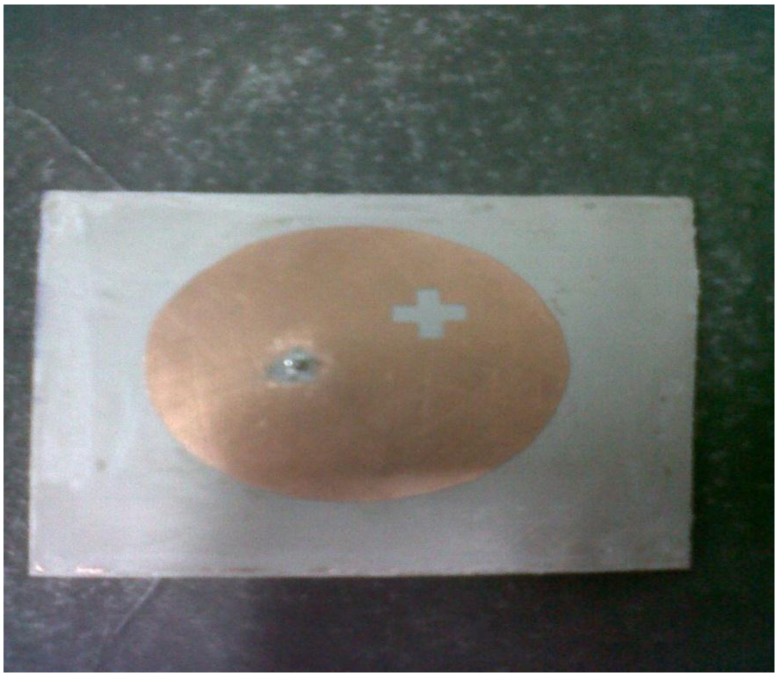


Fig.6.2 Fabricated antenna

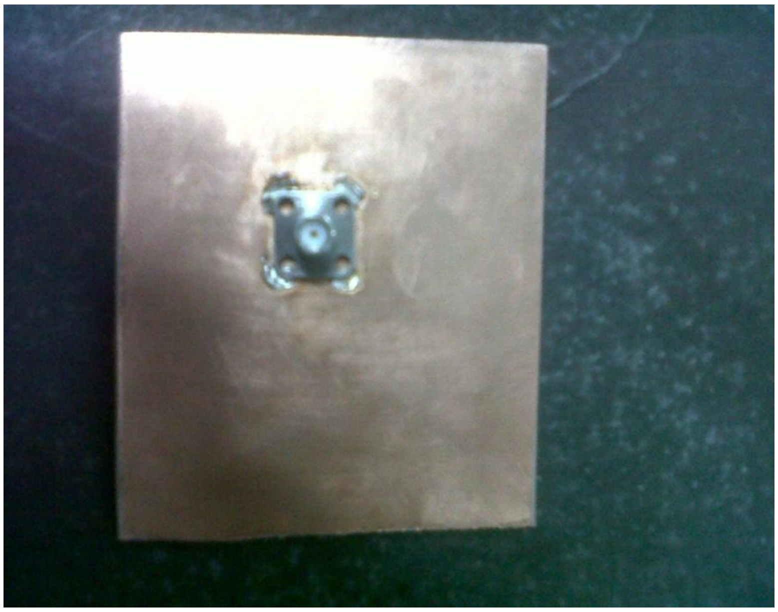


Fig.6.3 Fabricated antenna with Coaxial Connector

6.3 Test & Measurement

Testing the antenna’s characteristics forms one of the most important activities in the whole process. Moreover, of all the measurements that is made with any kind of circuit, the most difficult and least understood are those of antennas. This is because, in the case of circuits like filters, amplifiers, etc. enough accuracy can be achieved even with bench top measurements. However, in the case of antennas, the surrounding environment plays a major role in deciding the accuracy of the tests being conducted and bench-top measurements are not feasible in most cases.

Generally, any antenna should be tested only in a place far removed from any objects that may cause spurious reflections, such that it is effectively in outer space. Since this is not possible under usual circumstances, at least a controlled environment is essential to make good antenna measurements. The most deleterious effect that any physical structure present in the test site would have on the measurement is that of multipath. This occurs when the signal bounces off from surrounding objects and interferes with the received signal from the direct path, resulting in a wrong measurement. The following tests are typical of any antenna measurement setup.

- S-parameter, typically the reflection coefficient.
- Gain, with reference to an isotropic source
- Radiation pattern, both azimuth and elevation cuts.
- Polarization

The first test that we did was to verify its S-parameters, typically the S11. S11 measurement as well as a reflection test from a fabricated antenna. This gives an idea how well the antenna is matched to the input over the frequency of operation. Ideally, S11 less than -10 dB would be good for an antenna operating over a wide bandwidth. However, this value depends on the kind of application for which the antenna is being designed. The Network Analyzer (NA) was calibrated to the input of the antenna (or end of the cable) over the 2-8 GHz frequency range.

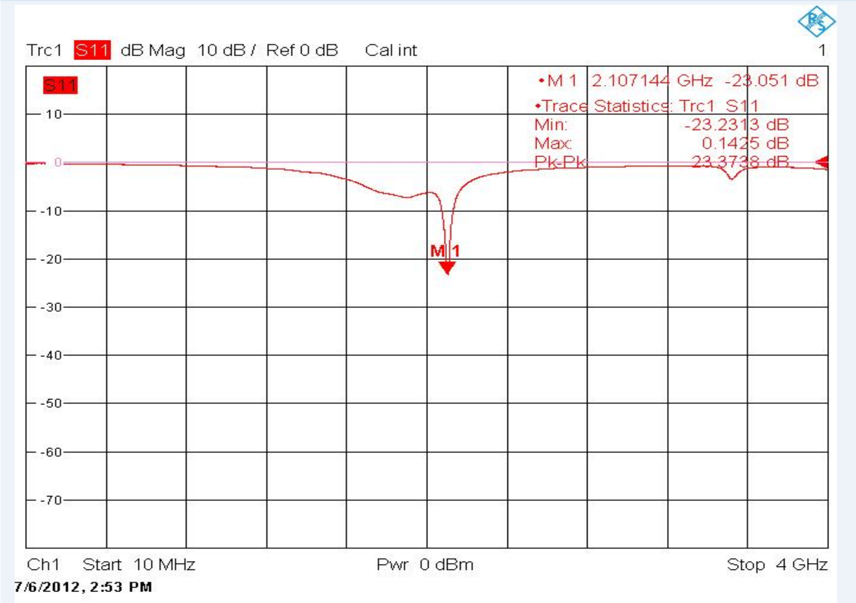


Fig.6.4 Return Loss (S11) Measured with N/W Analyzer

6.4 Pattern measurements

The knowledge of the exact beam directivity/gain pattern of the antenna will help us in determining the antenna performance in a cluttered environment. The antenna pattern helps us to gauge the amount of clutter that is going to be intercepted and their relative power levels.

"An antenna pattern is a graphical representation of the field magnitude at a fixed distance from an antenna as a function of direction". Antenna pattern measurements typically consist of the 'Antenna Under Test' (AUT) and a standard antenna with a known S11, radiation and polarization characteristics. As a result of reciprocity of transmit and receive patterns of antennas, measurements of gain and radiation patterns can be made with the test antenna used either as a transmitting or a receiving antenna.

But usually, for practical reasons, the AUT is used as a receiving antenna with the transmitting antenna located at a specified location. The source antenna thus provides a constant illumination of the test antenna whose output varies with its angular position. Thus the rule to have in mind is that it is the pattern of the rotated antenna that is being measured. Figure illustrates the point just discussed.

A complete representation of the radiation characteristics of the antenna would require measurement at all possible angles. The antenna patterns could be displayed in many possible ways. However, usually only the azimuth and the elevation cuts are performed which provides a good visualization of the actual 3-D pattern of the antenna.

Fig. 6.5 Radiation pattern measurement setup

Antenna measurements should be made in free-space conditions. A facility to measure the antenna radiation characteristics is called an antenna range. One of the most important aspects any antenna range is that the source antenna should illuminate a plane wave over the surface of the test antenna. This means that the magnitude and the phase of the incident wavefront must be uniform over the surface of the test antenna. Any deviations from this setup would result in errors in the gain and Source Antenna Test Antenna pattern measurement. The source should also have sufficient beamwidth so that it is able to illuminate the whole of the test antenna with very little reaching the surroundings and at the same time, not being so narrow that it induces an amplitude taper across the test antenna. By positioning both the source as well as the test antennas well beyond their respective far-field distances, the spherical wavefront, having traversed so far away from its source, could be assumed as a plane wavefront. Another major aspect in any antenna range setup is the proximity to potential clutter. This could be a major factor influencing the antenna measurements as a reflection from the ground/objects could interfere with the direct-path signal and cause erroneous nulls/peaks resulting in errors in the measurement.

Hence, care should be taken to mount the two antennas as far removed from any obstacles in the vicinity. With the knowledge of the distance between the two antennas, their height above the ground could then be determined such that any multipath signal reaching the test antenna would have no detrimental effect on the received signal.

The NA - HP 8522D is operated in the continuous-wave (CW) mode at the desired frequency with an output power level of -5 dBm so that it could be used to feed the transmitting antenna. The NA is connected to the transmitting antenna through a 10 feet UTi FLEX cable. At the receiver end, the outputs of the antenna are connected to the power combiner which is connected to a spectrum analyzer (SA) for measuring the power level at the transmit frequencies. The noise floor of the SA is set to a minimum to increase the sensitivity of the spectrum analyzer.

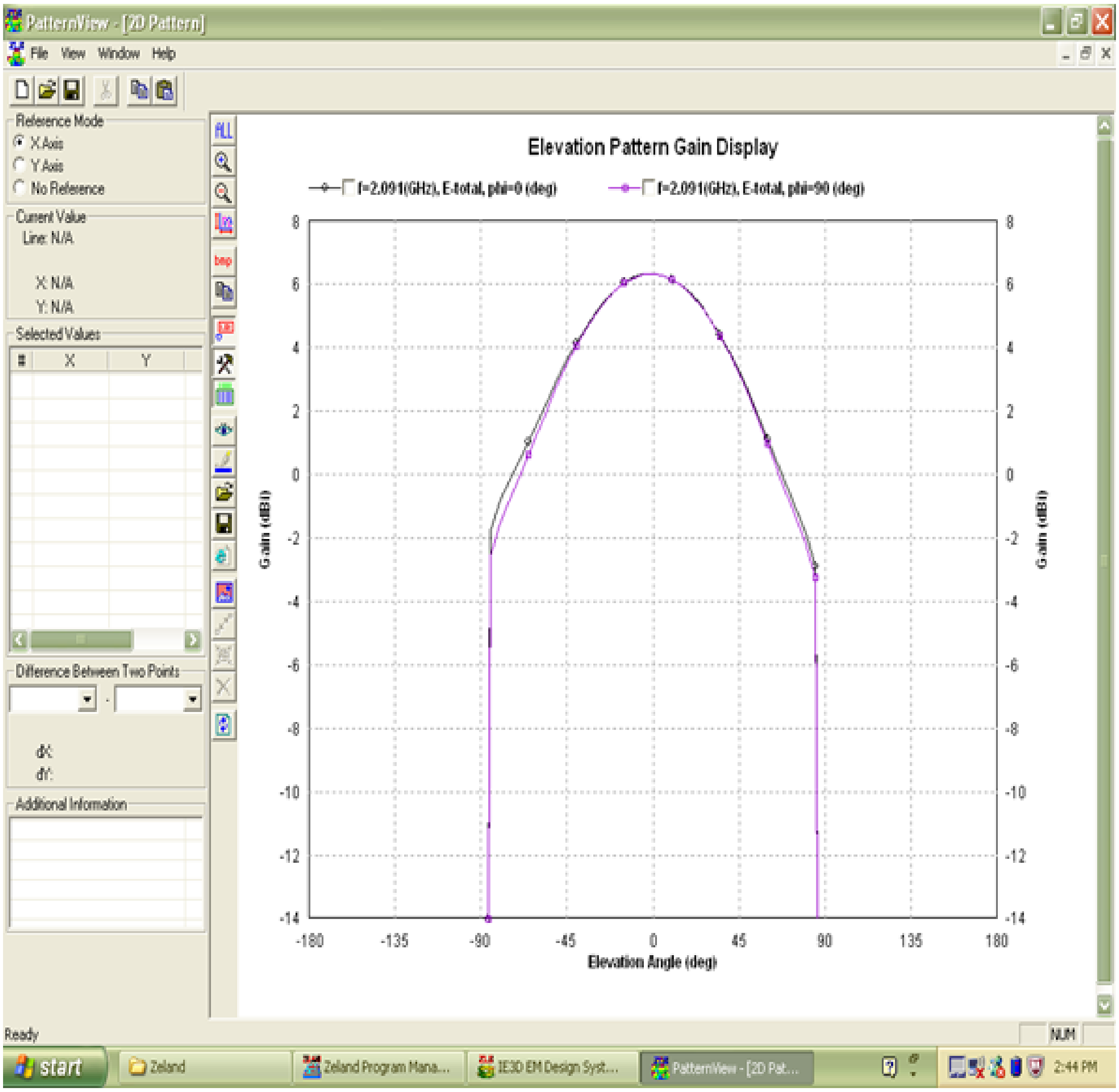
Signal Generator generate the signal:
Anritsn Made - upto 40 GHz.
Frequency is set to 2.091 GHz
level is set to L= +10 dbm.

Spectrum Analyzer:
Agilent-50Ω
Frequency set to 2.091.
With Span of 0.1GHz
Transmitted Power (PT) =1.67 dbm
Recived Power (PR) = Maximum Magnitude = -33.50 dbm
Gain of Transmitting Antenna (GT) = 8.5dbm
Distance between both antennas(R) =196 cm.

Fig.6.6 Spectrum analyzer

Fig.6.7Antenna setup

6.5 Comparison of Result



Reference Mode
● X Axis
○ Y Axis
○ No Reference

Current Value
Line: N/A
X: N/A
Y: N/A

Fig.6.8 Elevation Pattern Gain Display

Elevation Pattern

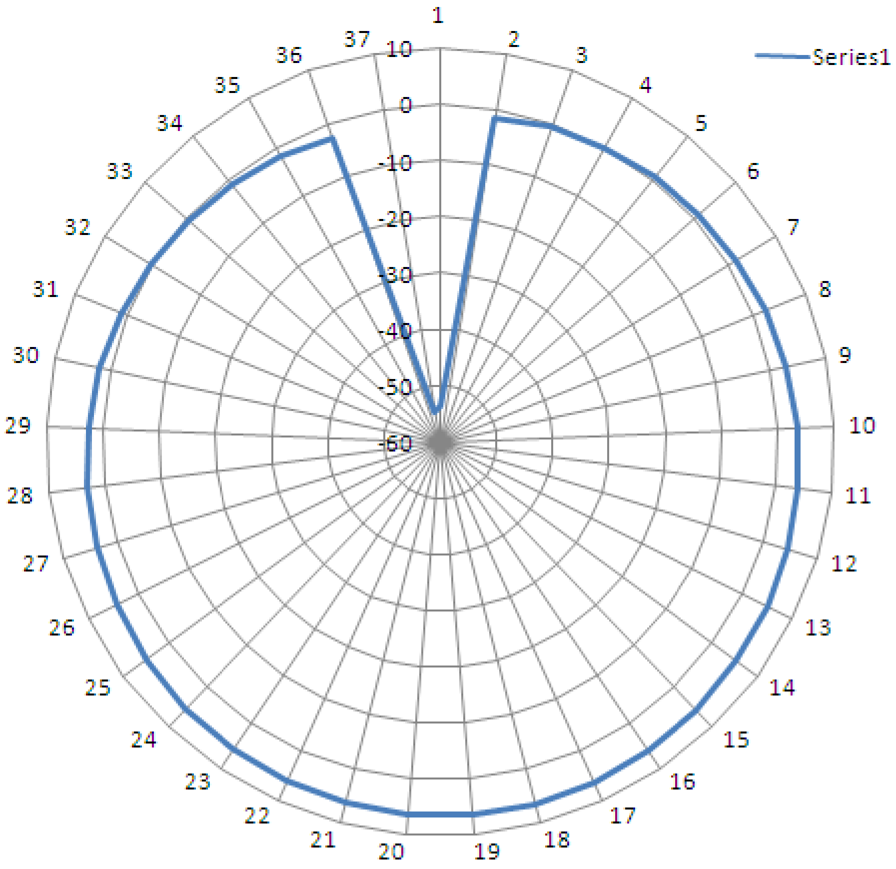


Fig.6.9 Radiation Pattern Simulated by IE3D Software

Elevation Pattern

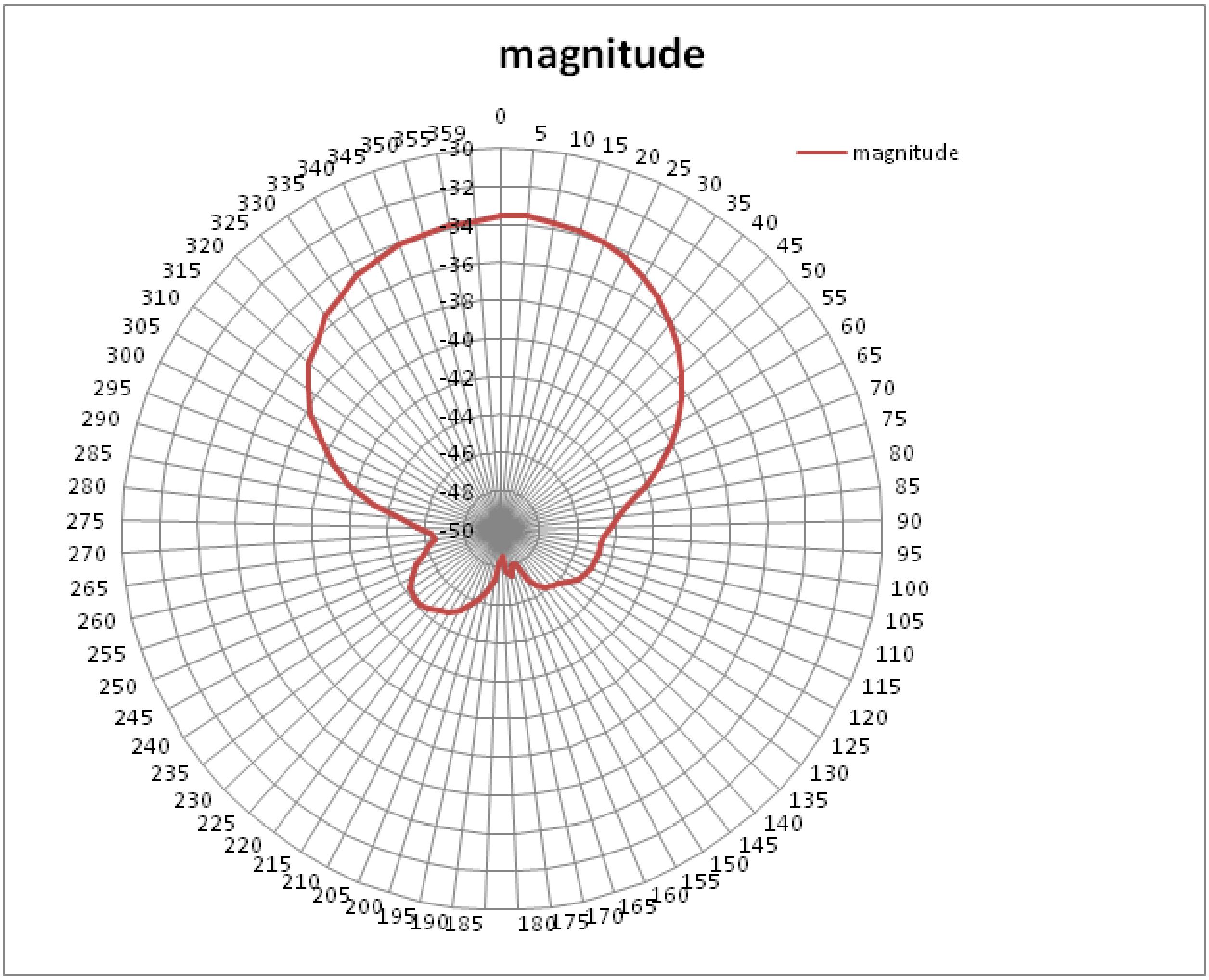
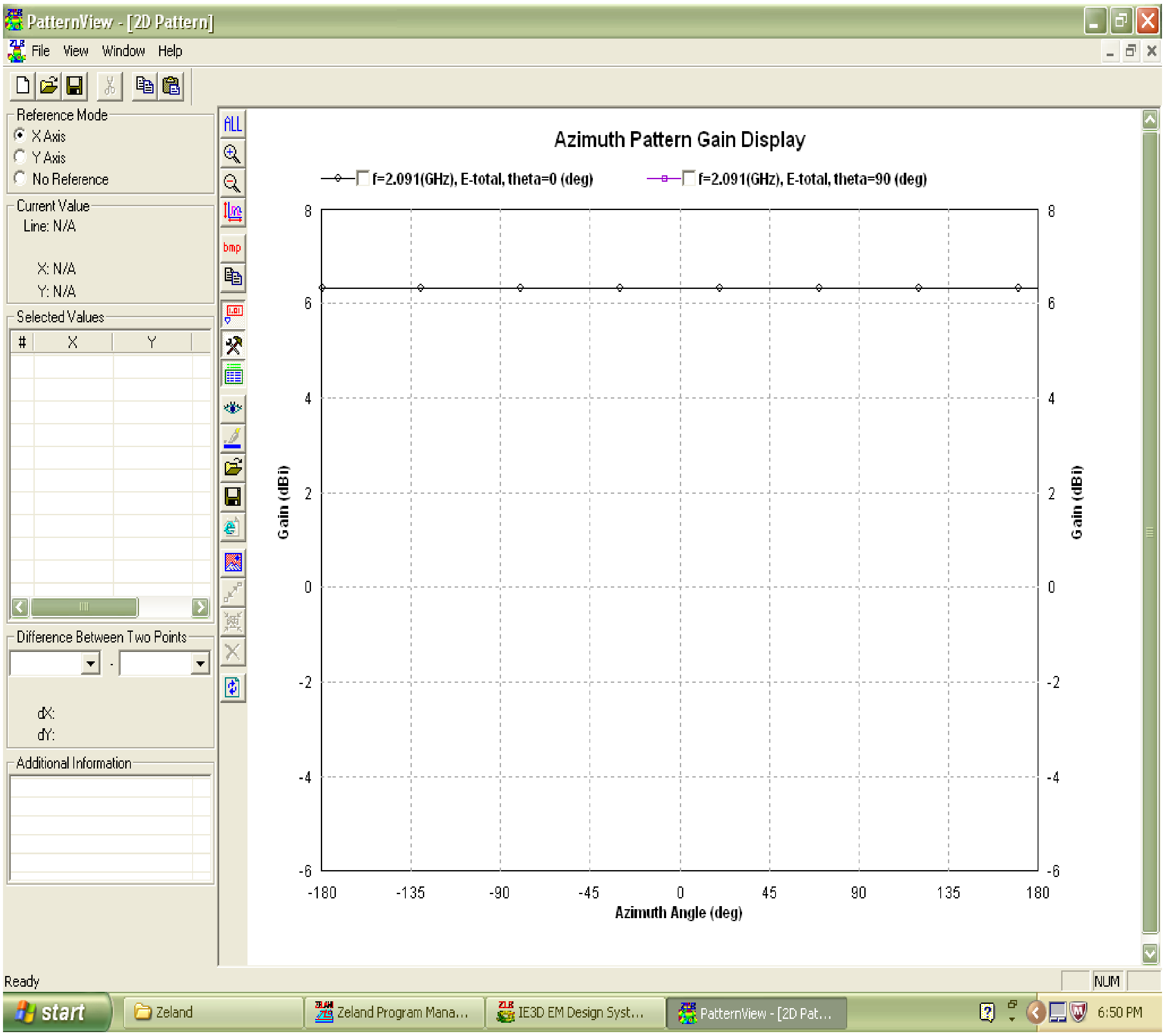


Fig.6.10 Radiation Pattern Practically Measured

Azimuth Pattern



Reference Mode
● X Axis
○ Y Axis
○ No Reference

Current Value
Line: N/A
X: N/A
Y: N/A

Fig.6.11 Azimuth Pattern Gain Display

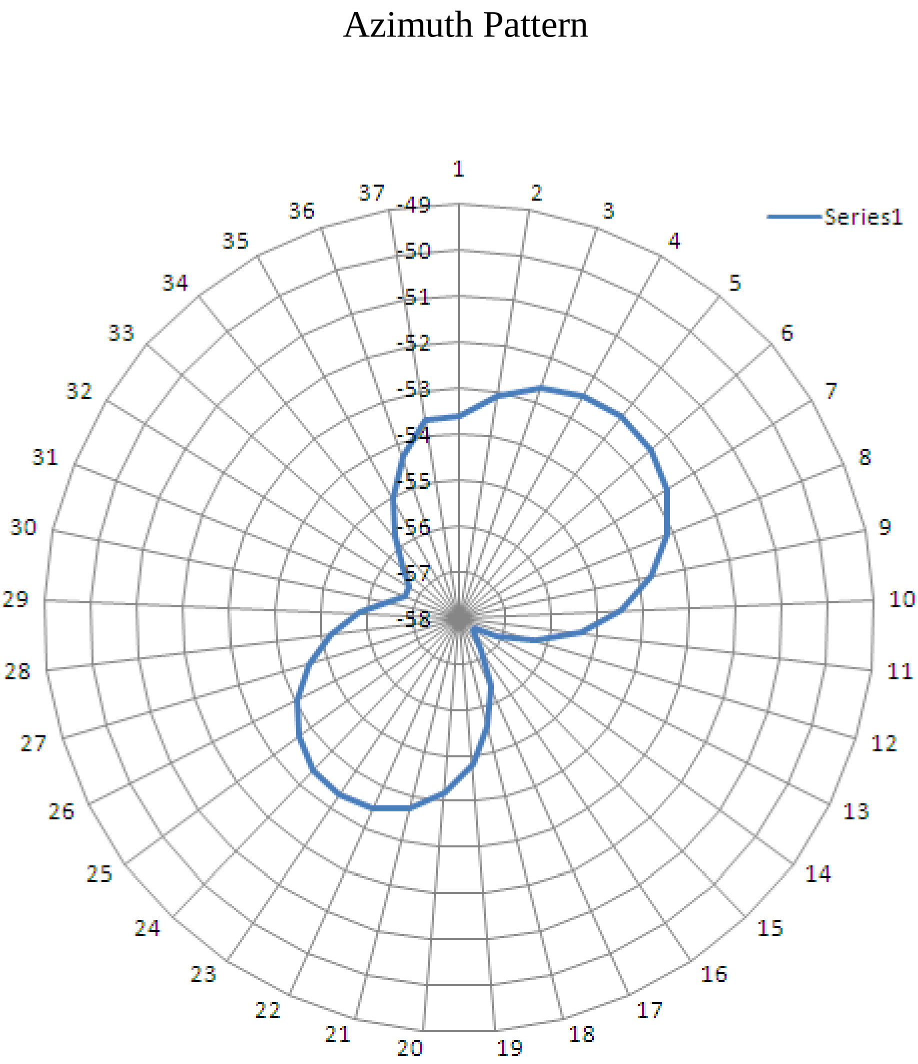


Fig.6.12 Radiation Pattern Simulated by IE3D Software

Azimuth Pattern

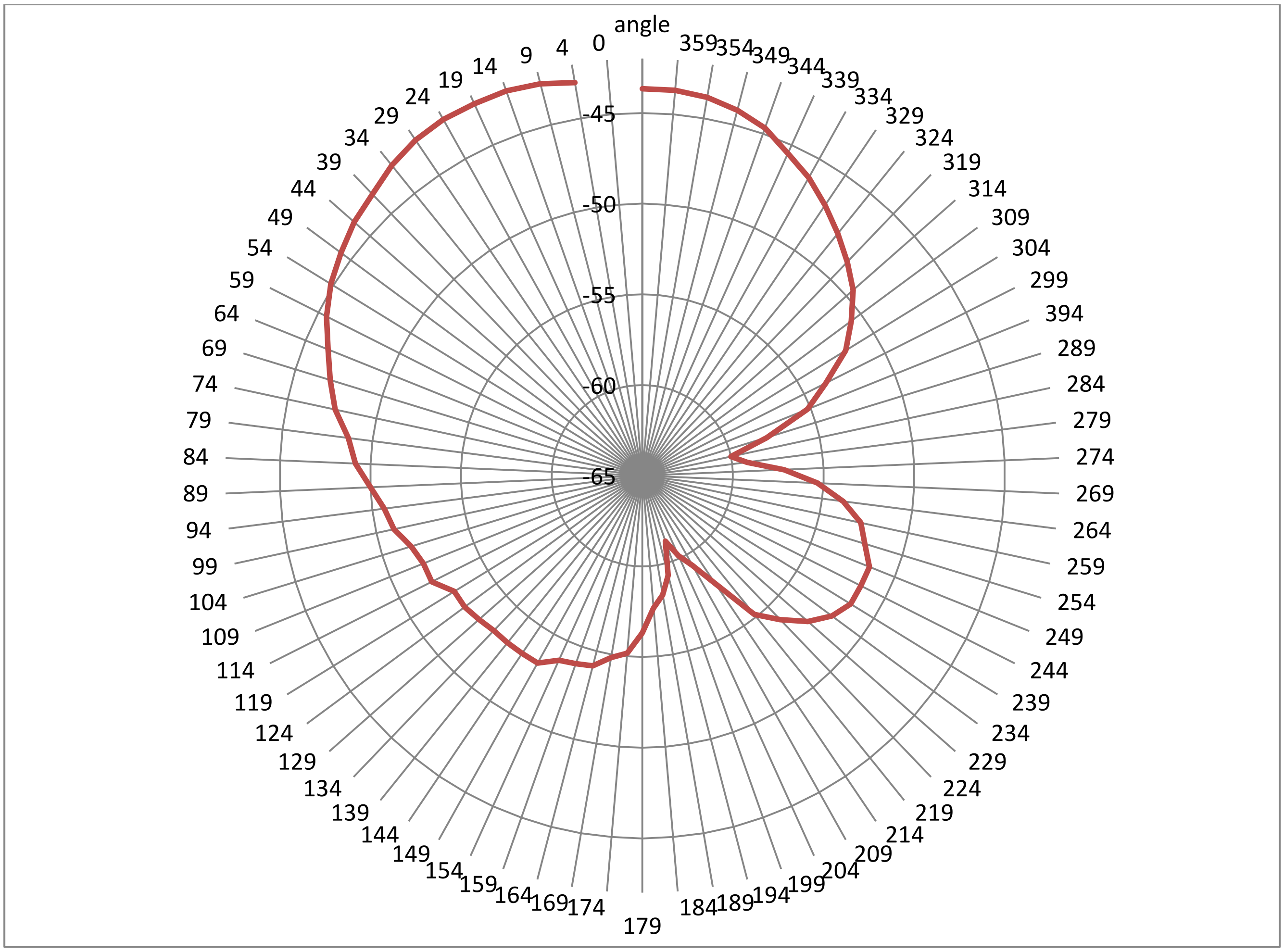


Fig.6.13 Radiation Pattern Practically Measured

CHAPTER 7
CONCLUSION AND FUTURE SCOPE

7.1 Conclusion

A compact cross-shaped slotted microstrip antenna has been presented for CP radiation. A cross-shaped microstrip antenna with different types of substrate with different electric permittivity have been studied and compared with respect to the variation of antenna parameters like, return loss , antenna efficiency, radiation efficiency, CP radiation etc with fixed antenna thickness. It is found that by selecting a suitable substrate specific antenna requirements can be met. It can be concluded that Benzocyclobuten is the most efficient amongst the eight dielectrics used in this cross-shaped compact antenna.It has all satisfactory values of all antenna parameters. By using benzocyclobuten we designed the cross-shaped slot microstrip antenna. By using Cross slot we reduced the size of the antenna. The antenna performance of the cross-shaped slot has been investigated as practically and analysis elevation ,azimuth and radiation pattern. This type of compact antenna is used in medical implanted and Road Vehicle Communications.

7.2 Suggestions for Future Work

Based on gathered observations while completing this thesis; topics were identified which would benefit for further investigation.

- We can Change the antenna property by using different types of slots in Compact Microstrip antenna .like circle , square ,U shape , swastika etc.

- We can use Electromagnetic band gap (EBG) structure for analysis and designing a New compact microstrip antenna and it is a better option for using in WLAN and Road Vehicle Communication.

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