DESIGN AND SIMULATION OF A 2.4 GHz MICROSTRIP PATCH ANTENNA

A dissertation submitted in partial fulfillment of requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering

ISLAMIC UNIVERSITY OF TECHNOLOGY
Organization of Islamic Cooperation (OIC)

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A Thesis Presented to
The Academic Faculty

By

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ABSTRACT

In this thesis, an optimization method based on IE3D is used to design an Inset Feed Linearly Polarized Rectangular Microstrip Patch Antenna. The aim of the thesis is to design an inset fed rectangular Microstrip Antenna and study the effect of antenna dimensions length (L) , width (W) and substrate parameters relative dielectric constant (ε_r) , substrate thickness on Radiation parameters of band width. 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. 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. In view of design, selection of the patch width and length are the major parameters along with the feed line depth. Desired Patch antenna design is initially simulated by using IE3D simulator. And Patch antenna is realized as per design requirements. With this design slightly modified, dual band frequencies can be obtained.

In this thesis, the resonant frequency is 2.4 GHz. At first, the dimensions of the rectangular patch antenna have been calculated. With those quantitative results then the simulation has been done. While doing simulation in practical case there has been a slight deviation in the desired frequency bandwidth. An optimization was taken to the dimensions for re-establish the frequency band at 2.4 GHz.

ACKNOWLEDGEMENT

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DECLARATION

Department of Electrical and Electronic Engineering

Submitted for B.Sc. in Electrical and Electronic Engineering

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The thesis is in acceptable. It fulfills all criteria set by the department.

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Chapter 1

INTRODUCTION

Aim and Objectives
Overview of Microstrip Antenna
Waves on Microstrip
Antenna Characteristics
Organization of the Thesis

CHAPTER 1

INTRODUCTION

Communication between humans was initiated with the introduction of vocal interaction. In those ages, communication was done with the help of electromagnetic spectrum of visible range resulting in a huge amount of insecurity and information loss. With the necessity of communication to a distant or remote place without damaging the information or compromising the security issues, the digital communication came into being. In such communications, the invisible ranges of electromagnetic spectrums are used which are far more reliable, safe and faster. One of humankind's greatest natural resources is the electromagnetic spectrum and the antenna has been instrumental in harnessing this resource.

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.

1.1 Aim and Objectives

Microstrip patch antenna used to send onboard parameters of article to the ground while under operating conditions. The aim of the thesis is to design an inset-fed rectangular Microstrip Patch Antenna and study the effect of antenna dimensions Length (L) , Width (W) and substrate parameters relative Dielectric constant (ε_r), substrate thickness (t) on the Radiation parameters of Bandwidth, s parameters and VSWR.

1.2 Overview of Microstrip Antenna

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.

1.3 Waves on Microstrip

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. 1.1) 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.

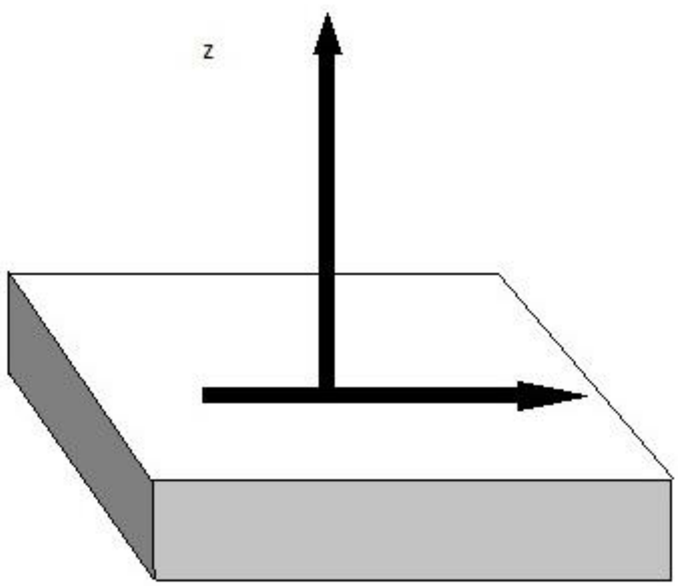


Fig 1.1: Hertz dipole on a microstrip substrate

1.4 Surface Waves

The waves transmitted slightly downward, having elevation angles θ between π/2and π -arcsin (1/√ε_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 (fig1.2). 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), say1/*r*, more slowly than space waves. 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, 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.

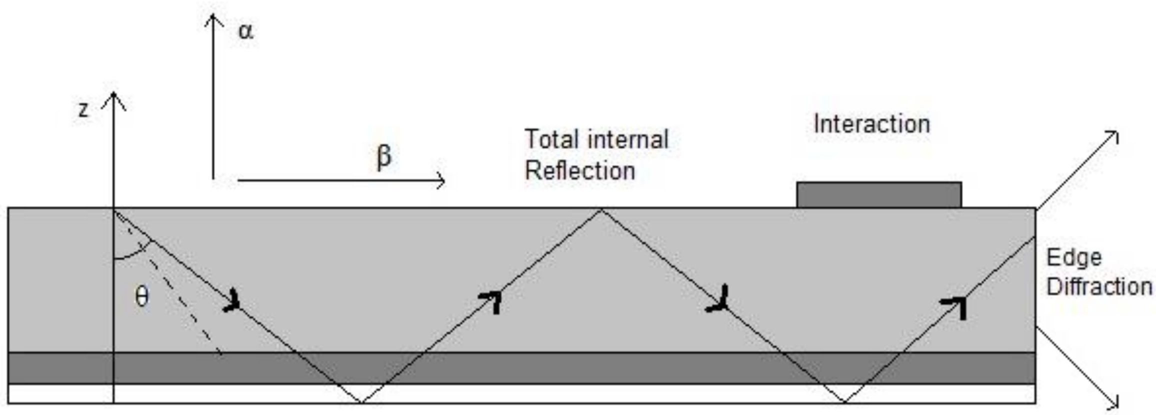


Fig1.2: Surface Waves

1.5 Leaky Waves

Waves directed more sharply downward, with θ angles between π - arcsin $(1/\sqrt{\varepsilon r})$ 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 1.3), hence their name laky 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. This apparent paradox is easily understood by looking at the figure 1.3; 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. 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.

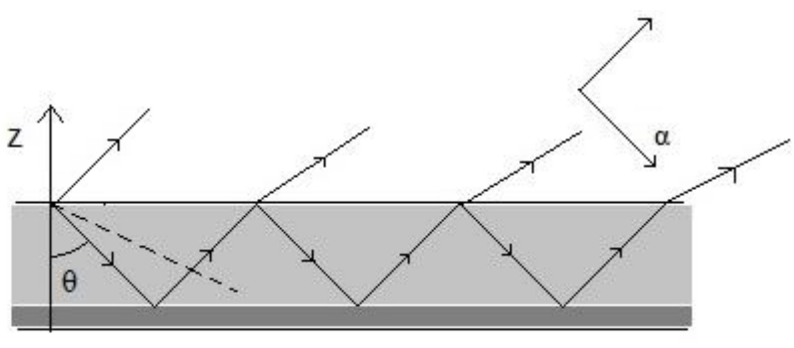


Fig 1.3: Leaky waves

1.6 Guided Waves

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. 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. On the other hand, this buildup of electromagnetic energy is not favorable for patch antennas, which behave like resonators with a limited frequency bandwidth.

1.7 Organization of the Thesis

In the first chapter, the introduction of is added along with some mechanism of transmission and radiation in microstrip. The aim and objective of this thesis included in this chapter as well.

In the second chapter, apart from the advantages and disadvantages of microstrip patch antenna, the various feeding techniques and models of analysis were listed.

The third chapter deals with the Radiation Parameters and the choice of substrate. The theory of radiation, various parameters and design aspects were discussed. All possible substrates for the design of microstrip antenna with their dielectric constant and permittivity are given.

The fourth chapter provides the design and development of microstrip antenna. It provides information about IE3d Software for simulation of Microstrip Antennas, which will be used for cross verification of results for designed antennas.

The fifth chapter gives the Conclusion to this project and suggests the future scope of work.

Chapter 2

MICROSTRIP PATCH ANTENNA

Introduction

Advantages and Disadvantages

Feed Techniques

Method of Analysis

Chapter 2

MICROSTRIP PATCH ANTENNA

2.1 INTRODUCTION:

This chapter presented an introduction to the microstrip patch antenna technology with its advantages and disadvantages. Next, a detailed explanation of microstrip patch antenna analysis and its theory are discussed. Finally, some feed modeling techniques are discussed and also the working mechanism is explained followed by feasible fabrication process.

2.2 MICROSTRIP ANTENNA:

A patch antenna (also known as a *rectangular microstrip antenna*) is a type of radio antenna with a low profile, which can be mounted on a flat surface. It consists of a flat rectangular sheet or "patch" of metal, mounted over a larger sheet of metal called a ground plane. The assembly is usually contained inside a plastic radome, which protects the antenna structure from damage. Patch antennas are simple to fabricate and easy to modify and customize. They are the original type of microstrip antenna described by Howell; the two metal sheets together form a resonant piece of microstrip transmission line with a length of approximately one-half wavelength of the radio waves. The radiation mechanism arises from discontinuities at each truncated edge of the microstrip transmission line. The radiation at the edges causes the antenna to act slightly larger electrically than its physical dimensions, so in order for the antenna to be resonant, a length of microstrip transmission line slightly shorter than one-half a wavelength at the frequency is used. A patch antenna is usually constructed on a dielectric substrate, using the same materials and lithography processes used to make printed circuit boards.

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.

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.

2.3 MICROSTRIP ANTENNA TECHNOLOGY:

In its most basic form, a microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side 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.

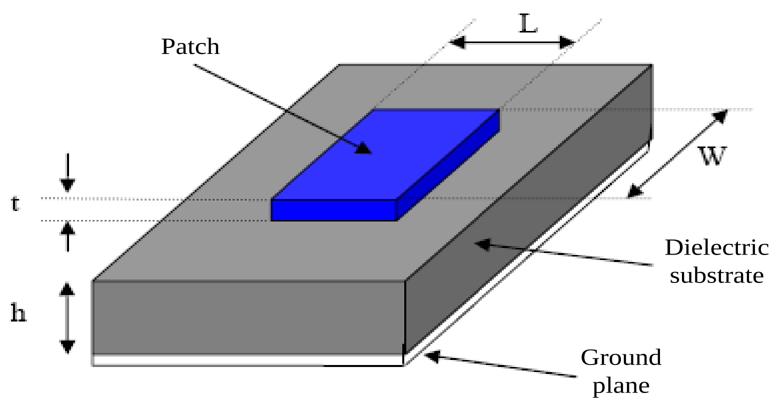


Figure 2.1 Structure of a microstrip patch antenna

Source: Chiou & Wong 2002

The radiating patch and the feed lines are usually photo etched on the dielectric substrate. In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape as shown in Figure 4.2. For a rectangular patch, the length L of the patch is usually $0.3333\lambda_0 < L < 0.5\lambda_0$, where λ_0 is the free-space wavelength (Pokuls et al. 1998). The patch is selected to be very thin such that $t << \lambda_0$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\lambda_0 \leq h \leq 0.05\lambda_0$. The dielectric constant of the substrate ε_r is typically in the range $2.2 \leq \varepsilon_r \leq 12$.

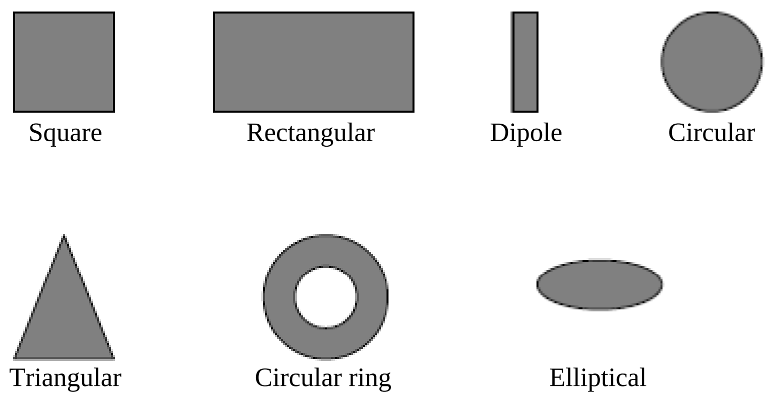


Figure 2.2 Common shapes of microstrip patch elements

Source: Garg et al. 2001

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 (Choi & Park 2006). However, such a configuration leads to a larger antenna size. In order to design a compact microstrip patch antenna, higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a compromise must be reached between antenna dimensions and antenna performance. 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 and pagers. The telemetry and communication antennas on missiles need to be thin and conformal and are often microstrip patch antennas. Another area where they have been used successfully is in satellite communication. Some of their principal advantages discussed by Balanis (1997) and Stutzman & Thiele (1998) are given below:

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

Microstrip patch antennas suffer from a number of disadvantages as compared to conventional antennas. Some of their major disadvantages discussed by Stutzman & Thiele (1998) and Garg et al. (2001) are given below:

i. Narrow bandwidth
ii. Low efficiency
iii. Low Gain
iv. Extraneous radiation from feeds and junctions
v. Poor end fire radiator except tapered slot antennas
vi. Low power handling capacity
vii. Surface wave excitation

Microstrip patch antennas have a very high antenna quality factor (Q). Q represents the losses associated with the antenna and a large Q leads to narrow bandwidth and low efficiency. 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 power loss since it is ultimately scattered at the dielectric bends and causes degradation of the antenna characteristics. However, surface waves can be minimized by use of bandgap structures as discussed by Lee et al. (1999). Other problems such as lower gain and lower power handling capacity can be overcome by using an array configuration for the elements.

2.4 Feeding Method :

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 fed 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).

2.5 Microstrip Line Feed

In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch as shown in Figure 2.3. 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.

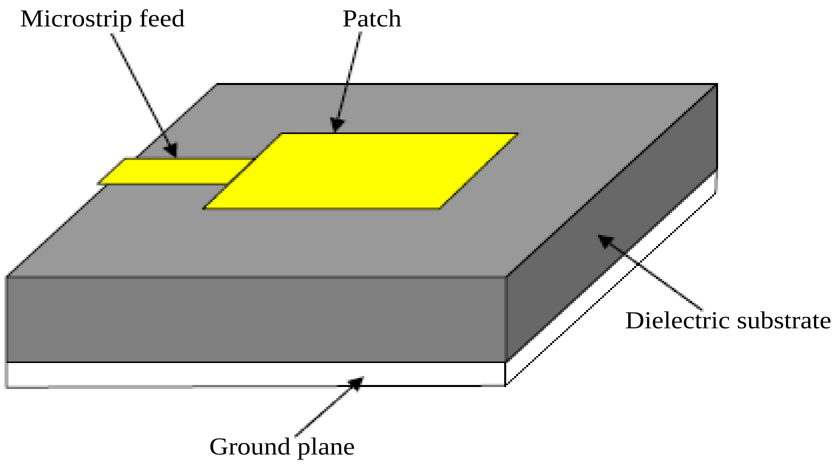


Figure 2.3   Microstrip line feed

Source: Balanis 1997

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna (Balanis 1997). The feed radiation also leads to undesired cross polarized radiation.

2.6 Coaxial Feed

The Coaxial feed or probe feed is a very common technique used for feeding microstrip patch antennas. As seen from Figure 2.4, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane. The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance.

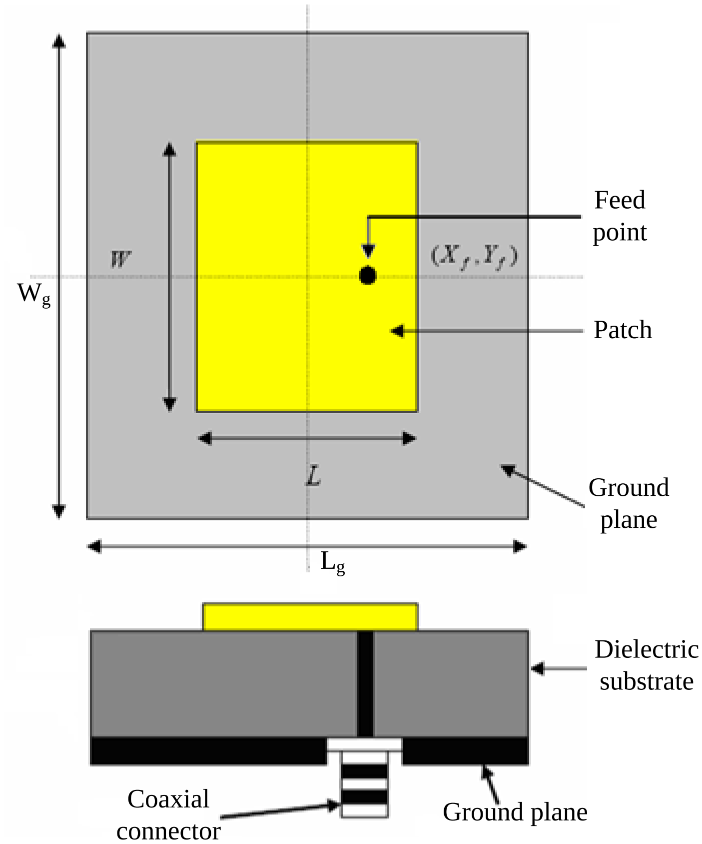


Figure 2.4 Coaxial probe feed

Source: Garg et al. 2001

This feed method is easy to fabricate and has low spurious radiation. However, its major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda_0$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems (Garg et al. 2001). 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. The non-contacting feed techniques which have been discussed below, solve these problems.

2.7 Aperture Coupled Feed

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 2.5. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane. The coupling aperture is usually centered under the patch, leading to lower cross-polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch (Gildas 1999). 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.

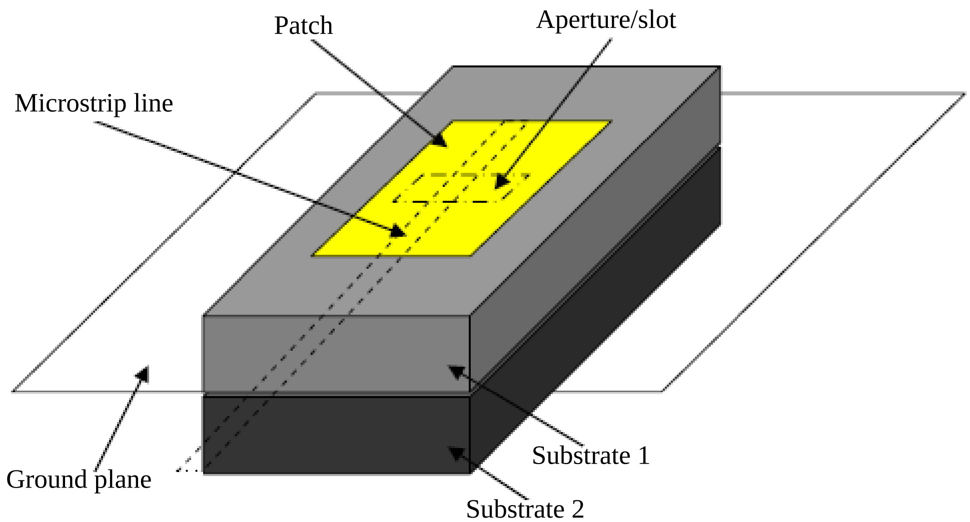


Figure 2.5 Aperture-coupled feed

Source: Gildas 1999

2.8 Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 2.6, 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.

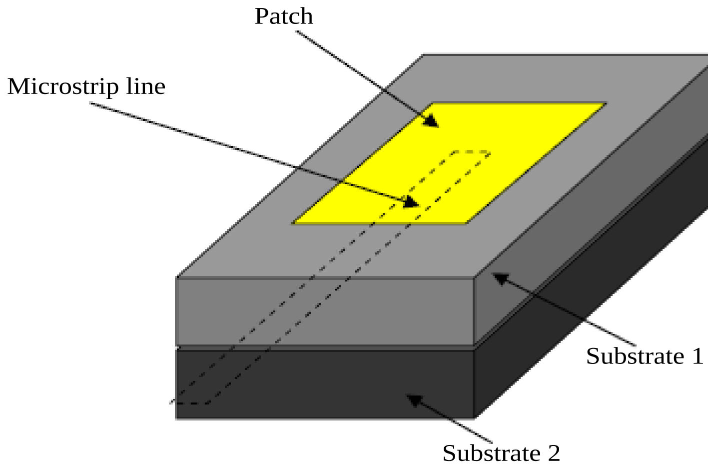


Figure 2.6 Proximity-coupled feed

Source: Balanis 1997

The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (Balanis 1997), due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances. Matching can be achieved by controlling the length of the feed line and the width-to-line ratio of the patch. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the antenna. Table 2.1 summarizes the characteristics of the different feed techniques.

Table 2.1 Comparisons of the different feed techniques

Characteristics	Microstrip line feed	Coaxial feed	Aperture coupled feed	Proximity coupled feed
Spurious feed radiation	More	More	Less	Minimum
Ease of fabrication	Easy	Soldering and drilling needed	Alignment required	Alignment required
Reliability	Better	Poor due to soldering	Good	Good
Impedance matching	Easy	Easy	Easy	Easy
Bandwidth	2-5%	2-5%	2-5%	13%

Source: Gildas 1999, Garg et al. 2001

Here an *Equivalent circuits of typical feeding methods are given below*

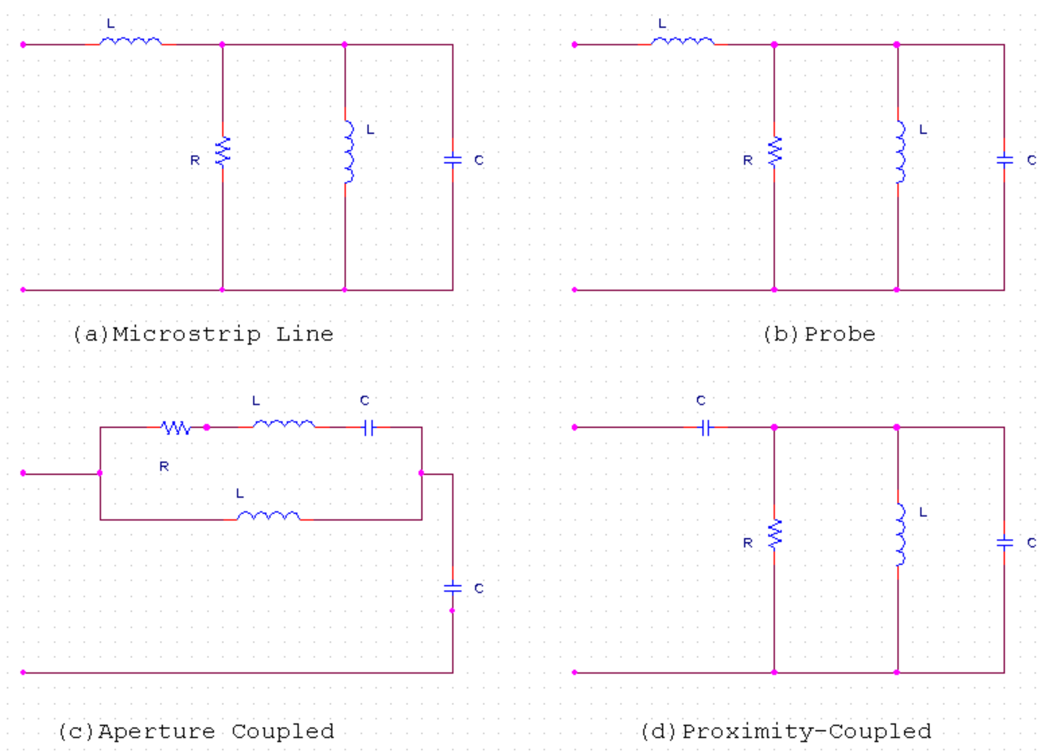


Figure 2.7 Equivalent circuits of typical feeding methods

Analytical Evaluation of a rectangular 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 a 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.

In common practice, microstrip antennas are evaluated using one of three analysis methods: 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. It can analyze single element, finite array, layered elements and arbitrary shaped element of microstrip antenna and also coupling effect of the antenna.

2.9 Transmission Line Model

This model represents the microstrip antenna by two slots of width *W* and height *h*, separated by a transmission line of length *L* as shown in Figure 2.8a. The microstrip is essentially a nonhomogeneous line of two dielectrics, typically the substrate and air. Hence, as seen from Figure 2.8b, most of the electric field lines reside in the substrate and parts of some lines in air.

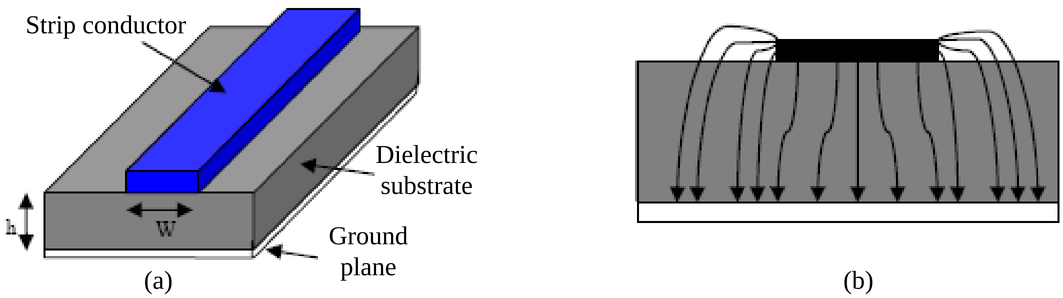


Figure 2.8Transmission line model a) microstrip line and b) electric field lines

Source: Balanis 1997

As a result, this transmission line cannot support pure 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_{r_eff}) must be obtained in order to account for the fringing and the wave propagation in the line. The value of ε_{r_eff} is slightly less then ε_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air as shown in Figure 2.8 above. The expression for ε_{r_eff} is given by Balanis (1997)

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

where

ε_{r_eff} = Effective dielectric constant

ε_r = Dielectric constant of substrate

h = Height of dielectric substrate

W = Width of patch

Consider Figure 2.9 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.

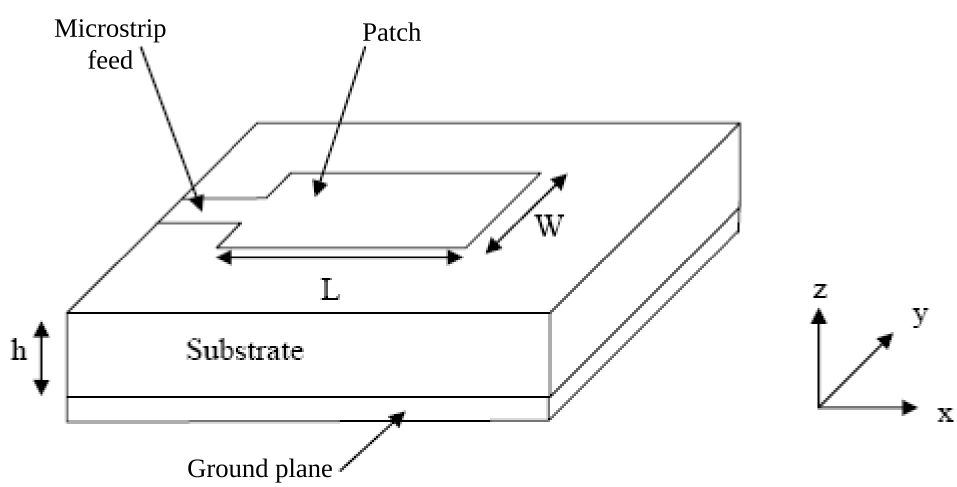


Figure 2.9 Rectangular microstrip patch antenna

Source: Tsoulos 2001

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 $\lambda_0/\sqrt{\varepsilon_{r\_eff}}$ where λ_0 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 2.10a, 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.

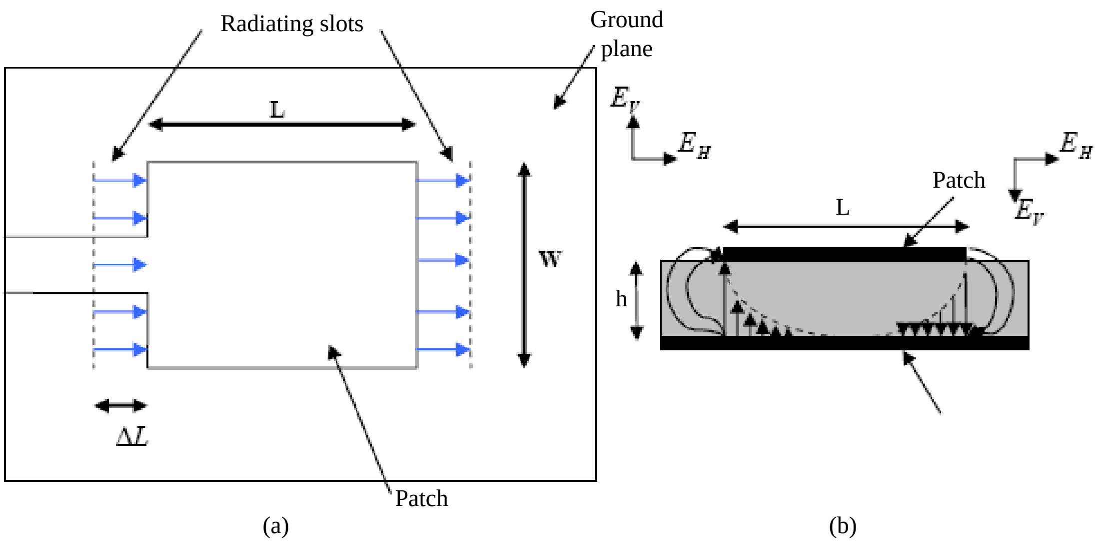


Figure 2.10 Microstrip patch antenna a) top view and b) side view

Source: Tsoulos 2001

It is seen from Figure 2.10b 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 2.10b), 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 Tsoulos (2001)

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

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

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

For a given resonance frequency f_0, the effective length is given by Garg et al. (2001)

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

For a rectangular microstrip patch antenna, the resonance frequency for any TM_{mn} mode is given by Garg et al. (2001)

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

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

For efficient radiation, the width W is given by Garg et al. (2001)

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

2.10 Cavity Model :

Although the transmission line model discussed in the previous section is easy to use, it has some inherent disadvantages. Specifically, 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.

In this model, the interior region of the dielectric substrate is modeled as a cavity bounded by electric walls on the top and bottom. The basis for this assumption is the following observations for thin substrates ($h << \lambda$).

• Since the substrate is thin, the fields in the interior region do not vary much in the *z* direction, i.e. normal to the patch.

• The electric field is *z* directed only, and the magnetic field has only the transverse components *Hx* and *Hy* in the region bounded by the patch metallization and the ground plane.

This observation provides for the electric walls at the top and the bottom.

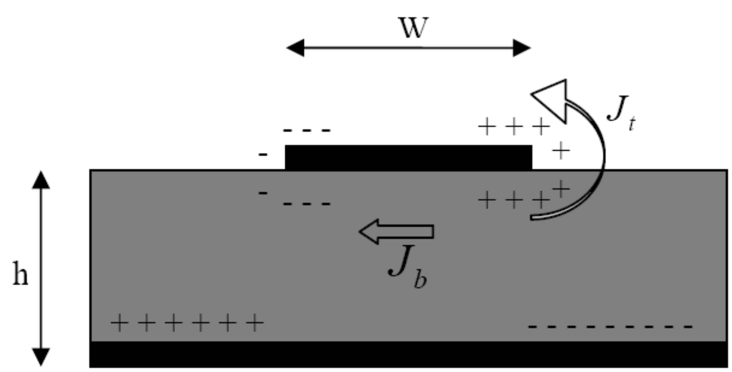


Figure 2.11 Charge distribution and current density creation on the microstrip patch

Consider Figure 2.11 shown above. When the microstrip patch is provided power, a charge distribution is seen on the upper and lower surfaces of the patch and at the bottom of the ground plane. This charge distribution is controlled by two mechanisms an attractive mechanism and a repulsive mechanism. The attractive mechanism is between the opposite charges on the bottom side of the patch and the ground plane, which helps in keeping the charge concentration intact at the bottom of the patch. The repulsive mechanism is between the like charges on the bottom surface of the patch, which causes pushing of some charges from the bottom, to the top of the patch. As a result of this charge movement, currents flow at the top and bottom surface of the patch. The cavity model assumes that the height to width ratio (i.e. height of substrate and width of the patch) is very small and as a result of this the attractive mechanism dominates and causes most of the charge concentration and the current to be below the patch surface. Much less current would flow on the top surface of the patch and as the height to width ratio further decreases, the current on the top surface of the patch would be almost equal to zero, which would not allow the creation of any tangential magnetic field components to the patch edges. Hence, the four sidewalls could be modeled as perfectly magnetic conducting surfaces. This implies that the magnetic fields and the electric field distribution beneath the patch would not be disturbed. However, in practice, a finite width to height ratio would be there and this would not make the tangential magnetic fields to be completely zero, but they being very small, the side walls could be approximated to be perfectly magnetic conducting .

Since the walls of the cavity, as well as the material within it are lossless, the cavity would not radiate and its input impedance would be purely reactive. Hence, in order to account for radiation and a loss mechanism, one must introduce a radiation resistance R_r and a loss resistance R_l. A lossy cavity would now represent an antenna and the loss is taken into account by the effective loss tangent δ_{eff} which is given as

$$\delta_{eff} = 1/Q_T \tag{4.7}$$

Q_T is the total antenna quality factor and has been expressed by Garg et al. (2001) in the form

$$\frac{1}{Q_T} = \frac{1}{Q_d} + \frac{1}{Q_c} + \frac{1}{Q_r} \tag{4.8}$$

Q_d represents the quality factor of the dielectric and is given by

$$Q_d = \frac{\omega_r W_T}{P_d} = \frac{1}{\tan\delta} \tag{4.9}$$

where

ω_r is the angular resonant frequency

W_T is the total energy stored in the patch at resonance

P_d is the dielectric loss

$\tan\delta$ is the loss tangent of the dielectric

Q_c represents the quality factor of the conductor and is given by

$$Q_c = \frac{\omega_r W_T}{P_c} = \frac{h}{\Delta} \tag{4.10}$$

where

P_c is the conductor loss

Δ is the skin depth of the conductor

h is the height of the substrate

Q_r represents the quality factor for radiation and is given by

$$Q_r = \frac{\omega_r W_T}{P_r} \tag{4.11}$$

where P_r is the power radiated from the patch.

Substituting equations (4.8), (4.9), (4.10) and (4.11) in equation (4.7), it found that

$$\delta_{eff} = \tan\delta + \frac{\Delta}{h} + \frac{P_r}{\omega_r W_T} \tag{4.12}$$

Thus, equation (4.12) describes the total effective loss tangent for the microstrip patch antenna.

2.11 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 Stutzman & Thiele (1998), 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. The basic form of the equation to be solved by the Method of Moment is

$$F(g) = h \qquad (4.13)$$

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 given by

$$g = \sum_{n-1}^{N} a_n g_n = a_1 g_1 + a_2 g_2 + ... + a_N g_N \qquad (4.14)$$

where a_n is an unknown constant and g_n is a known function usually called a basis or expansion function.

Chapter 3

ANTENNA PARAMETERS & DEFINITIONS

Gain

Directivity

Antenna Polarization

Input Impedance

Voltage Standing Wave Ratio

Return Loss

Bandwidth

Quality Factor

CHAPTER 3

Antenna Parameters and Definitions

3.1 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. 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.

3.2 Directivity

Directivity is the same as gain, but with one difference. It does not include the effects of power lost (inefficiency) in the antenna. If an antenna were lossless (100 % efficient), then the gain and directivity (in a given direction) would be the same.

3.3 Antenna Polarization

Polarization is one of the fundamental characteristics of any antenna. The term polarization has several meanings. In a strict sense, it is the orientation of the electric field vector E at some point in space. If the E-field vector retains its orientation at each point in space, then the polarization is linear; if it rotates as the wave travels in space, then the polarization is circular or elliptical. In most cases, the radiated-wave polarization is linear and either vertical or horizontal. At sufficiently large distances from an antenna, beyond 10 wavelengths, the radiated, far-field wave is a plane wave. The polarization of an antenna is the polarization of the radiated fields produced by an antenna, evaluated in the far field. Hence, antennas are often classified as "Linearly Polarized" or a "Right Hand Circularly Polarized Antenna".

This simple concept is important for antenna to antenna communication. First, a horizontally polarized antenna will not communicate with a vertically polarized antenna. Due to the reciprocity theorem, antennas transmit and receive in exactly the same manner. Hence, a vertically polarized antenna transmits and receives vertically polarized fields. Consequently, if a horizontally polarized antenna is trying to communicate with a vertically polarized antenna, there will be no reception.

3.4 Input impedance:

There are three different kinds of impedance relevant to antennas. 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 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 resonant32 frequency as shown in Figure 3.1. Typically, the feed reactance is very small, compared to the resonant resistance for thin substrates.

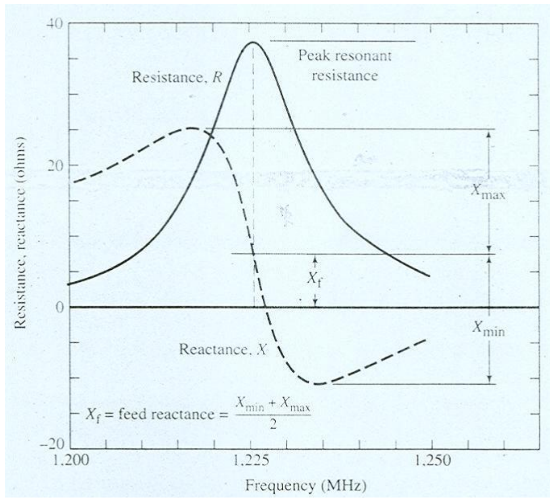


Figure 3.1 Typical variation of resistance and reactance of rectangular Microstrip antenna versus frequency

3.5 Voltage Standing Wave Ratio:

As electromagnetic wave travels through different parts of the antenna system, from the source to the feed line to the antenna and finally to the free space, they may encounter differences in impedance at each interface. Depending on the impedance match, some fraction of the wave's energy will reflect back to the source, forming a standing wave in the feed line. The ratio of the maximum power to the minimum power in the wave can be measured and is called the standing wave ratio (SWR). 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. If the reflection coefficient is given by Γ, then the VSWR is defined as:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

3.6 Physical Meaning of VSWR

VSWR is determined from the voltage measured along a transmission line leading to an antenna. VSWR is the ratio of the peak amplitude of a standing wave to the minimum amplitude of a standing wave, as seen in the following Figure:

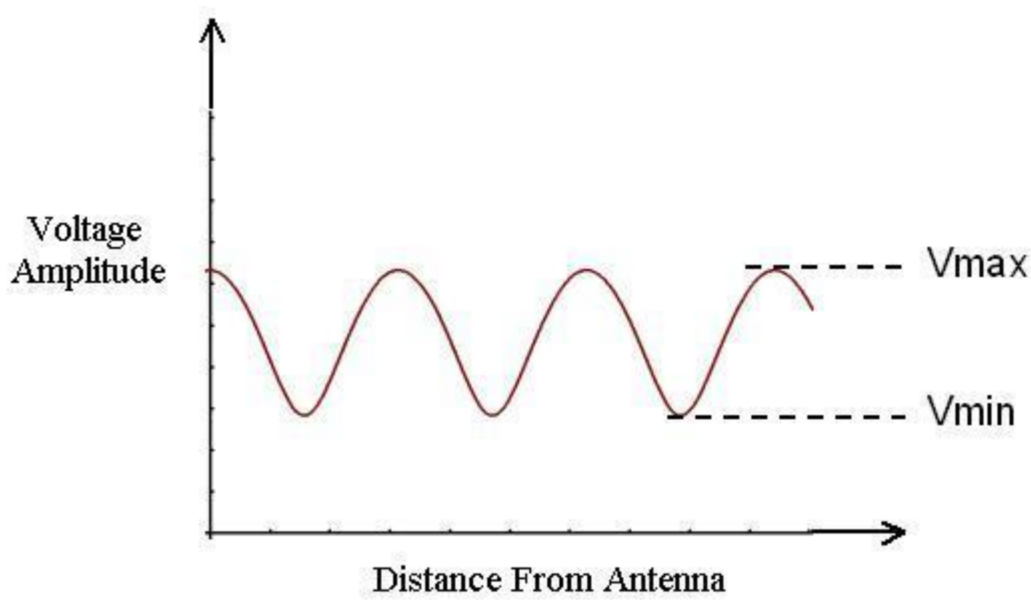


Figure 3.2. Voltage Measured Along a Transmission Line.

When an antenna is not matched to the receiver, power is reflected (so that the reflection coefficient, Γ, is not zero). This causes a "reflected voltage wave", which creates standing waves along the transmission line. The result are the peaks and valleys as seen in Figure 1. If the VSWR = 1.0, there would be no reflected power and the voltage would have a constant magnitude along the transmission line.

3.7 Return loss

The return loss is another way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the antenna from the transmission line.
The relationship between SWR and return loss is the following:

Return Loss (in dB) =20log10(SWR\ SWR-1)

3.8 Bandwidth:

Bandwidth is another fundamental antenna parameter. Bandwidth describes the range of frequencies over which the antenna can properly radiate or receive energy. Often, the desired bandwidth is one of the determining parameters used to decide upon an antenna. For instance, many antenna types have very narrow bandwidths and cannot be used for wideband operation. Bandwidth is typically quoted in terms of VSWR.

For instance, an antenna may be described as operating at 100-400 MHz with a VSWR<1.5. Also, the radiation pattern will vary with frequency. In general, the shape of the radiation pattern does not change radically.

There are also other criteria which may be used to characterize bandwidth. This may be the polarization over a certain range, for instance, an antenna may be described as having circular polarization with an axial ratio < 3dB (less than 3 dB) from 1.4-1.6 GHz. This polarization bandwidth sets the range over which the antenna's operation is approximately circularly polarized. For broadband antennas, the bandwidth is usually expressed as the ratio of the upper to lower frequencies of acceptable operation. However, for narrowband antennas, the bandwidth is expressed as a percentage of the bandwidth.

3.9 S parameter

S-parameters describe the input-output relationship between ports (or terminals) in an electrical system. For instance, if we have 2 ports (intelligently called Port 1 and Port 2), then S12 represents the power transferred from Port 2 to Port 1. S21 represents the power transferred from Port 1 to Port 2. In general, SNM represents the power transferred from Port M to Port N in a multi-port network.

A port can be loosely defined as any place where we can deliver voltage and current. So, if we have a communication system with two radios (radio 1 and radio 2), then the radio terminals (which deliver power to the two antennas) would be the two ports. S11 then would be the reflected power radio 1 is trying to deliver to antenna 1. S22 would be the reflected power radio 2 is attempting to deliver to antenna 2. And S12 is the power from radio 2 that is delivered through antenna 1 to radio 1. In practice, the most commonly quoted parameter in regards to antennas is S11. S11 represents how much power is reflected from the antenna, and hence is known as the reflection coefficient (sometimes written as gamma: Γ or return loss. If S11=0 dB, then all the power is reflected from the antenna and nothing is radiated. If S11=-10 dB, this implies that if 3 dB of power is delivered to the antenna, -7 dB is the reflected power. The remainder of the power was "accepted by" or delivered to the antenna. This accepted power is either radiated or absorbed as losses within the antenna. Since antennas are typically designed to be low loss, ideally the majority of the power delivered to the antenna is radiated.

3.10 Quality Factor

The quality factor is a figure-of-merit that representative of the antenna losses. Typically there are radiation, conduction, dielectric and surface wave losses. 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. For very thin substrates $h \ll \ell$ of arbitrary shapes including rectangular, there approximate formulas to represent the quality factors of the various losses. It is evident that the bandwidth increases as the substrate height increases. However, the radiation efficiency of the patch antenna described by the ratio of power radiated over the input power decreases as normalized height of the substrate increased.

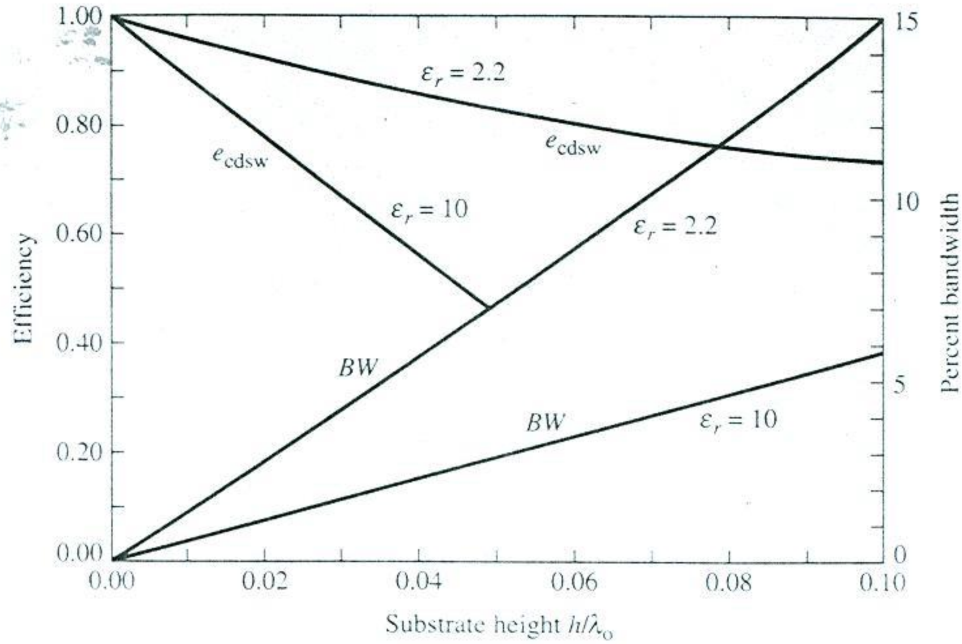


Figure 3.3 Efficiency and bandwidth versus substrate height at constant resonant frequency for Rectangular Microstrip patch for two different substrates.

CHAPTER 4

MICROSTRIP PATCH ANTENNA DESIGN AND RESULTS

Procedure

Figures

Results

CHAPTER 4

MICROSTRIP PATCH ANTENNA
DESIGN and RESULTS

4.1 Rectangular Microstrip Antenna

The rectangular patch antenna is approximately a one-half wavelength long section of rectangular Microstrip transmission line. When air is the antenna substrate, the length of the rectangular Microstrip antenna is approximately one-half of a free-space wavelength. As the antenna is loaded with a dielectric as its substrate, the length of the antenna decreases as the relative dielectric constant of the substrate increases. The resonant length of the antenna is slightly shorter because of the extended electric "fringing fields" which increase the electrical length of the antenna slightly.

4.2 Center Frequency 2.4GHz

A single element of rectangular patch antenna can be designed for the 2.4 GHz resonant frequency. In the typical design procedure of the Microstrip antenna, the desired resonant frequency, thickness and dielectric constant of the substrate are known or selected initially. In this design of rectangular Microstrip antenna, a RT Duriod dielectric material(ε_r=3.4) with dielectric loss tangent of 0.002 is selected as the substrate with 10mm height. Then, a patch antenna that operates at the specified operating frequency, $f_0 =$ 2.4 GHz can be designed by the following steps using transmission line model equations. The antenna is existed by the INSET feed away from the center of the patch.

The essential parameter specifications for the design of the rectangular microstrip patch antenna are as in Table 4.1.

4.3 Shape And The Corresponding Single Band Rectangular Patch Antenna

Shape	Single Band Rectangular
Frequency of operation	2.4 GHz
Dielectric constant of substrate	3.4
Feeding method	Inset feed
VSWR	1.5:1
Beamwidth Azimuth Zenith	<100 <100
Gain	5 dBi - 8dBi
Polarization	Linear

Table 4.1 Design parameter specifications of microstrip antenna.

4.4 Procedure Of Drawing Rectangle And Simulation

4.4.1 Drawing a rectangle and a microstrip feed line.

The first step is done as follows:

1. At First We draw a rectangle with the help of IE3D Software.
2. The dimension of the rectangle is 30 mm by 21 mm.This is the standard for our microstrip patch antenna.
3. We have drawn a several rectangle and do our simulation but got the best result in 30 mm by 21 mm.
4. Then we draw the feed line with the help of another rectangle which is much more smaller compared to the main rectangle.

5. The feed line that we use here is the probe feed.
6. The z dimension of the top surface is Ztop=1.524mm(60 mils)
7. The dielectric constant of the layer is 3.4.
8. We use 0.002 as the value of loss tangent.
9. We will draw the structure in multiple stages which are described as follows.
10. The Feeding microstrip line is a 50Ω line and the impedance of the antenna is matched to 50Ω by using an inset feed.
11. We can draw the layout manually or use the available scripts to draw them.In this case we will draw them using the scripts.
12. The main rectangle figure looks like the following:

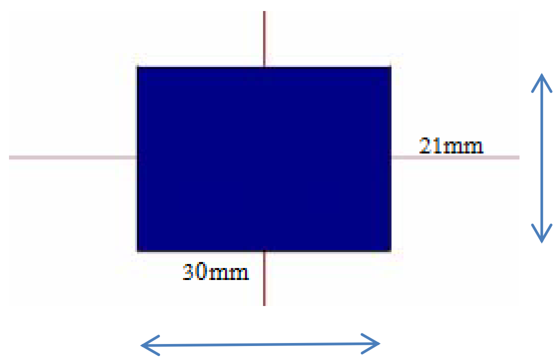


Figure 4.1: outline of the main rectangle

13. After that we create a small rectangle of 12.25 for the X-offset and -13 for the Y-offset values.and then again we insert -13 in the Y-offset field.
14. Now the rectangle has been formed
15. Same rectangle we will insert just beside tthis rectangle which we created right now in the bottom right corner of the main rectangle.
16. The figure looks like the following:

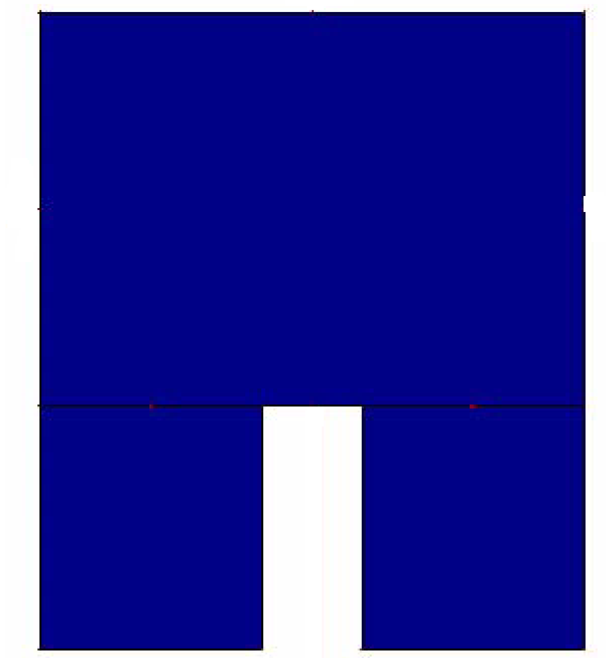


Figure 4.2: rest of the structure

17.Now we insert 0 in the Y-offset and 17.75 in the Y-

offset field to draw another rectangle.

18.The figure looks like the following:

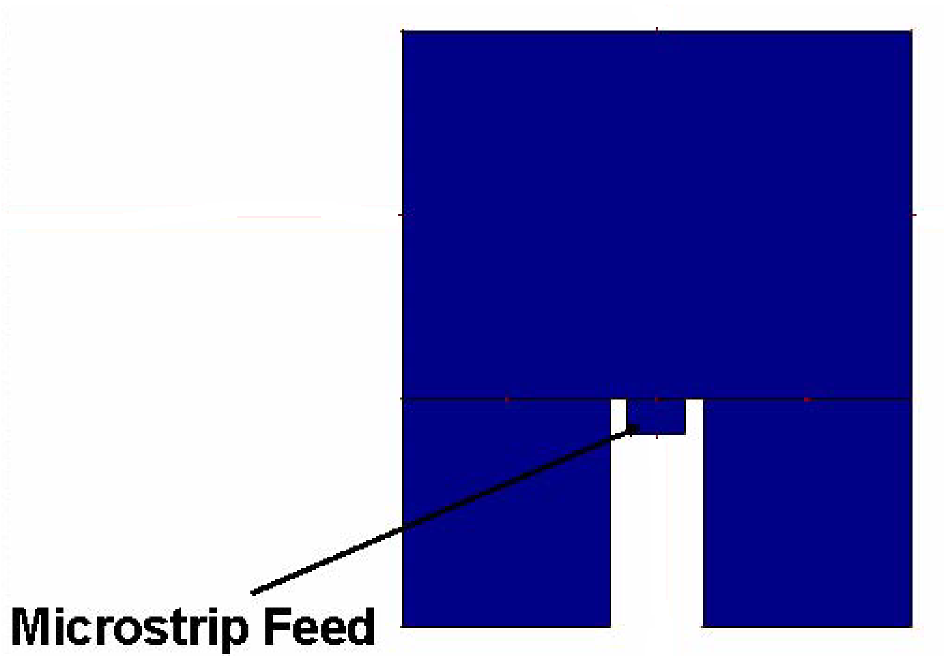
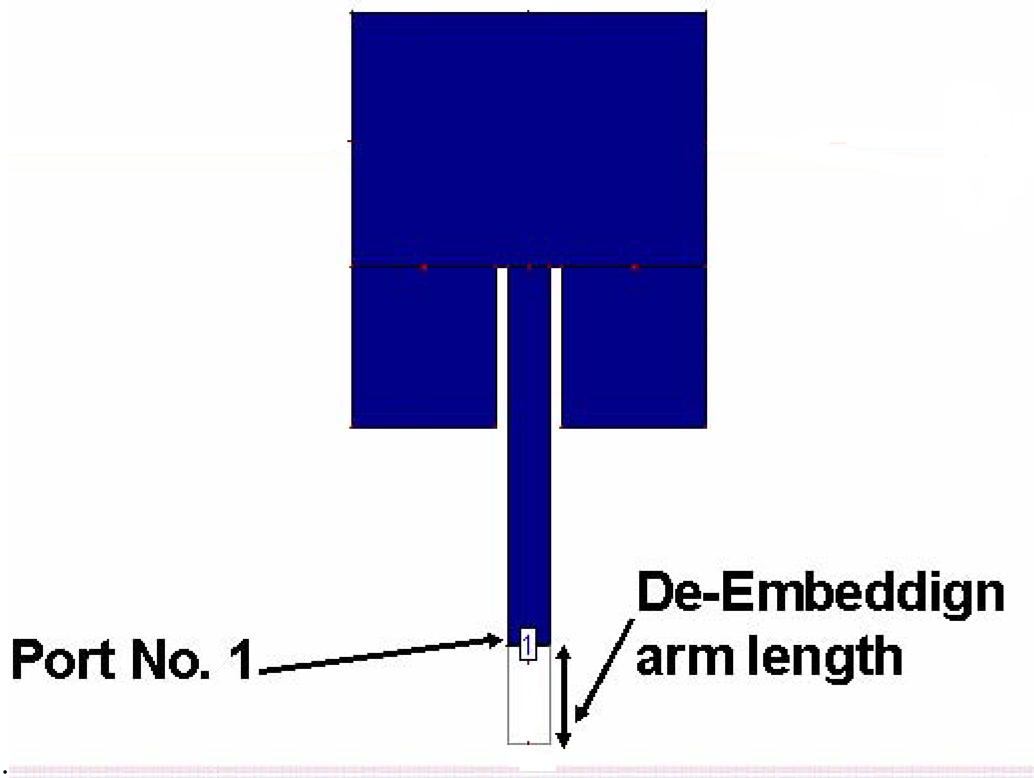


Figure 4.3: Rectangle with the microstrip feed

19.Now the task is to draw the main feeding line .in this case we start to draw a small rectangle with the two opposing corners located at (-1.75mm,-10.5mm) and (1.75mm,-12mm).

20.Finally the figure looks like the



following: e

following:

Figure 4.3: Rectangle with the microstrip feed line

4.4.2 Simulation Procedure

1.Here our operating frequency is 2.4GHz.But we have taken the maximum frequency is 3GHz.

2.The cells per wavelength is 10.it determines the density of the mesh.the higher the number of cells per wavelength the higher the accuracy of simulation.in many simulations using 20 to 30 cells per wave length should provide enough accuracy.

3.Now the second simulation and in this case inspite of simulating at 2.4GHz we will simulate at 1 to 3GHz.

4.In this case the cells per wavelength will be increased and that is 70.

5.In this case the time require is comparatively much more than the previous simulation.

6.We will get a number of simulation results such as VSWR,S-Parameters,Radiation Pattern etc.

7.These results are shown in the next section.

4.5: Results:

Formulas:

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

$\varepsilon_{r\_eff} = effecteive\ di - electric\ constant$

$\varepsilon_r = di - electric\ constant\ of\ substrate$

h=Height of di-electric substrate

W=Width of di-electric substrate

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

3.$\Delta L = 0.412h\frac{(\varepsilon_{r\_eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{r_{eff}}-0.258)(\frac{W}{h}+0.8)}$

From the equation 2 **W=21.0625mm**

From the equation 3 $\Delta L = 0.004108$**mm**

Finally L=28mm

4.6 LIST OF FIGURES:

Structural View:

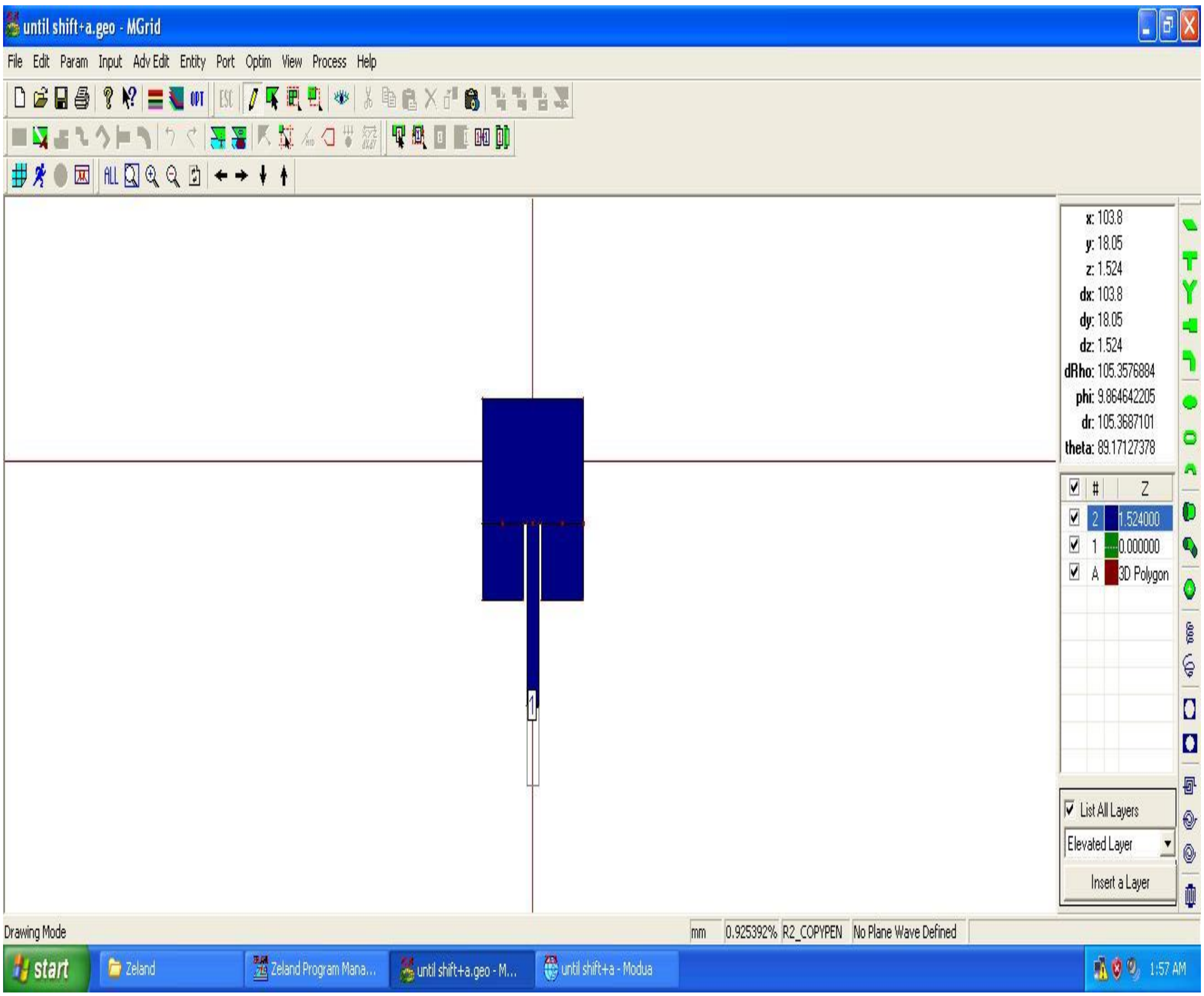


Figure 4.3: Structural View

Maintaining the original dimension the db & s-paeameters and the VSWR plot are shown below:

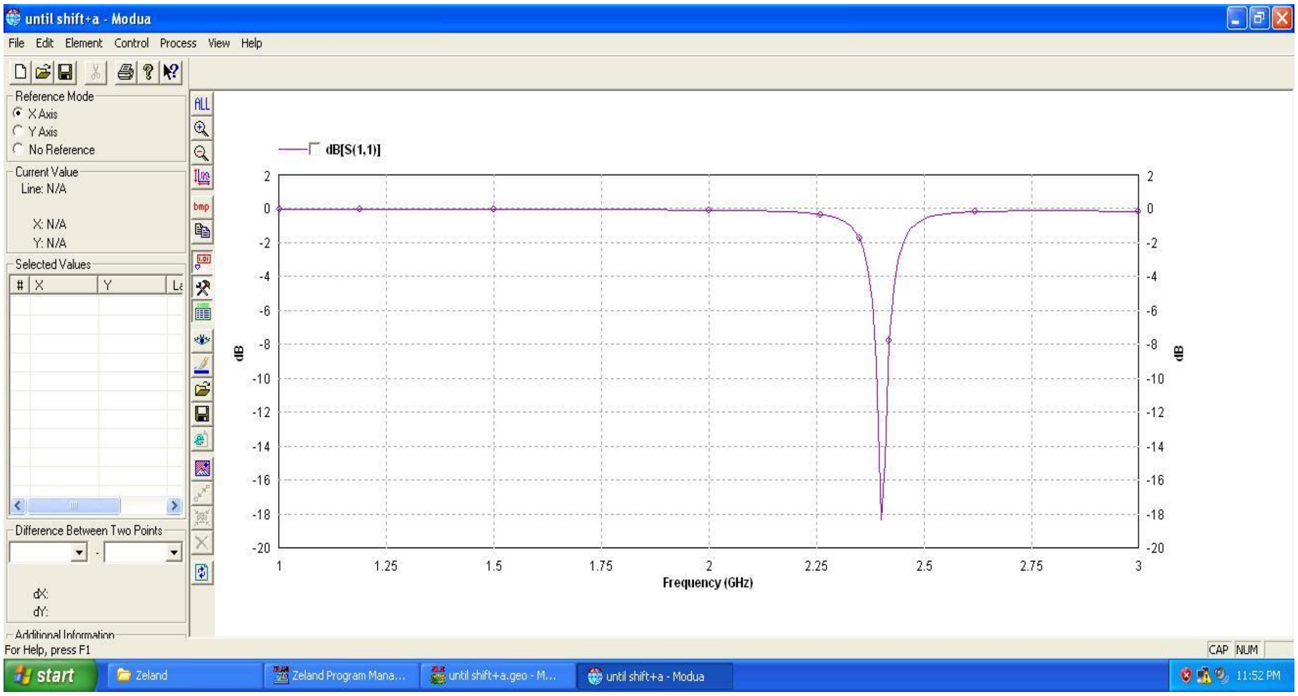


Figure 4.6: : *Figure of dB & phase of s- parameter Maintaining the original dimensions*

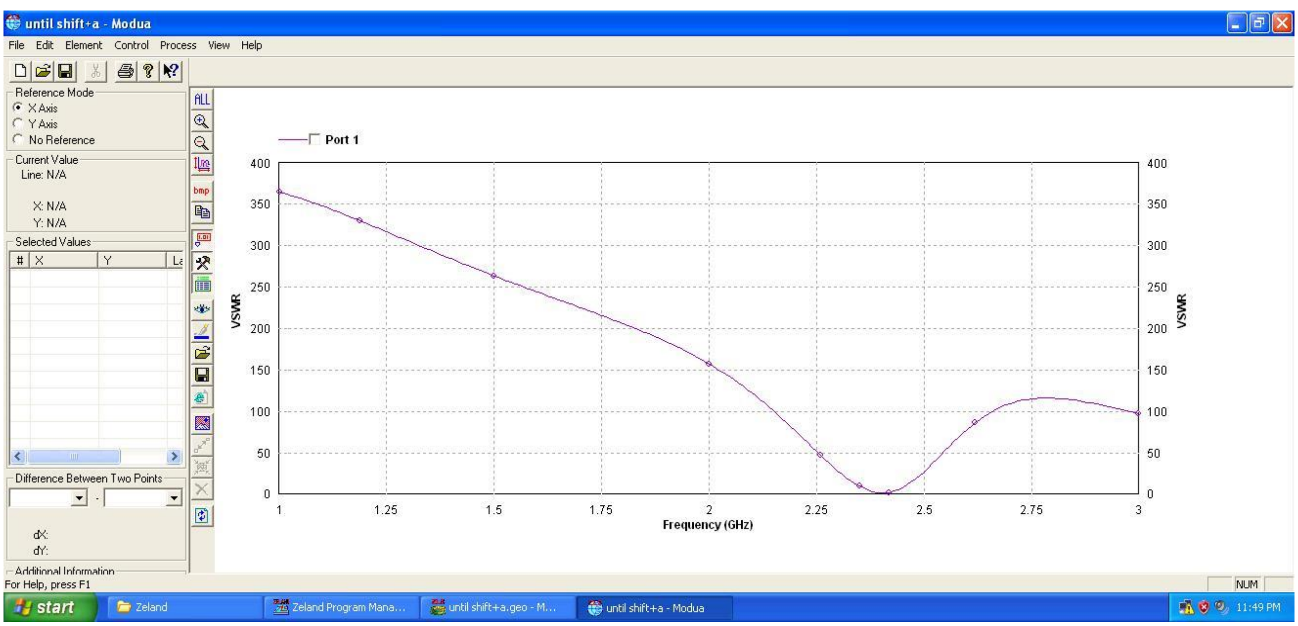


Figure 4.7: *VSWR Maintaining the original dimensions*

when we decreased the dimension by 20% the resonant frequency was 2.65GHz

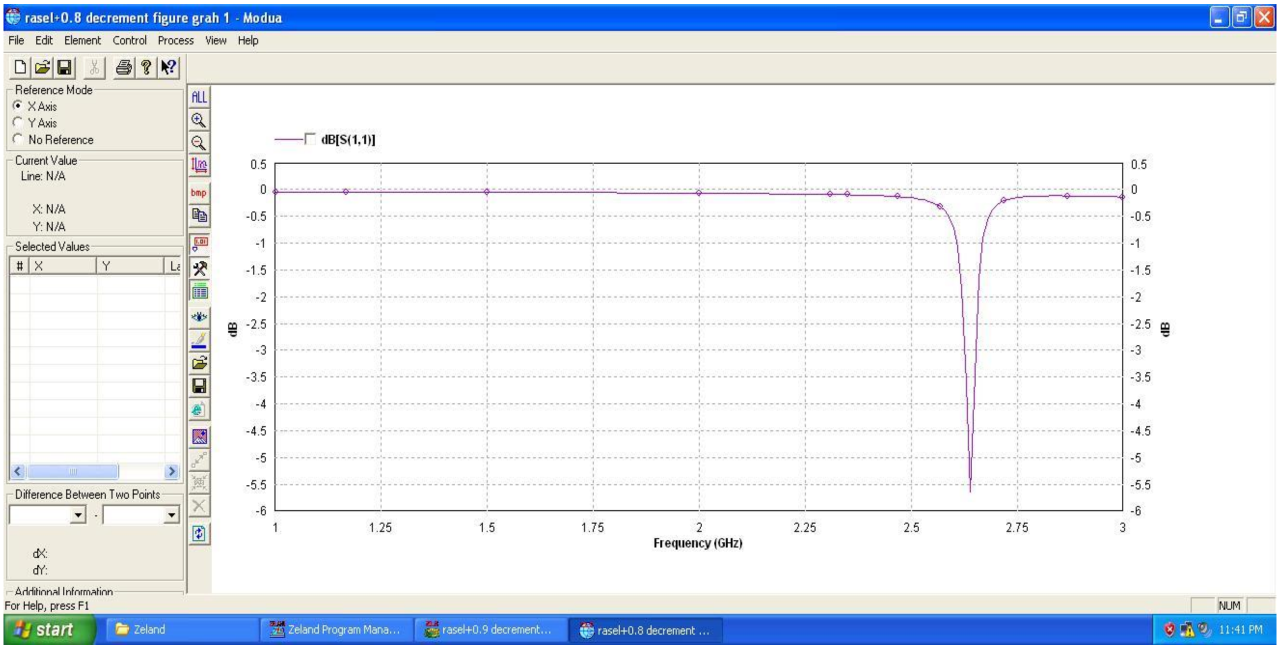


Figure 4.8: : *Figure of dB & phase of s- parameter decreasing the dimension by 20%***.**

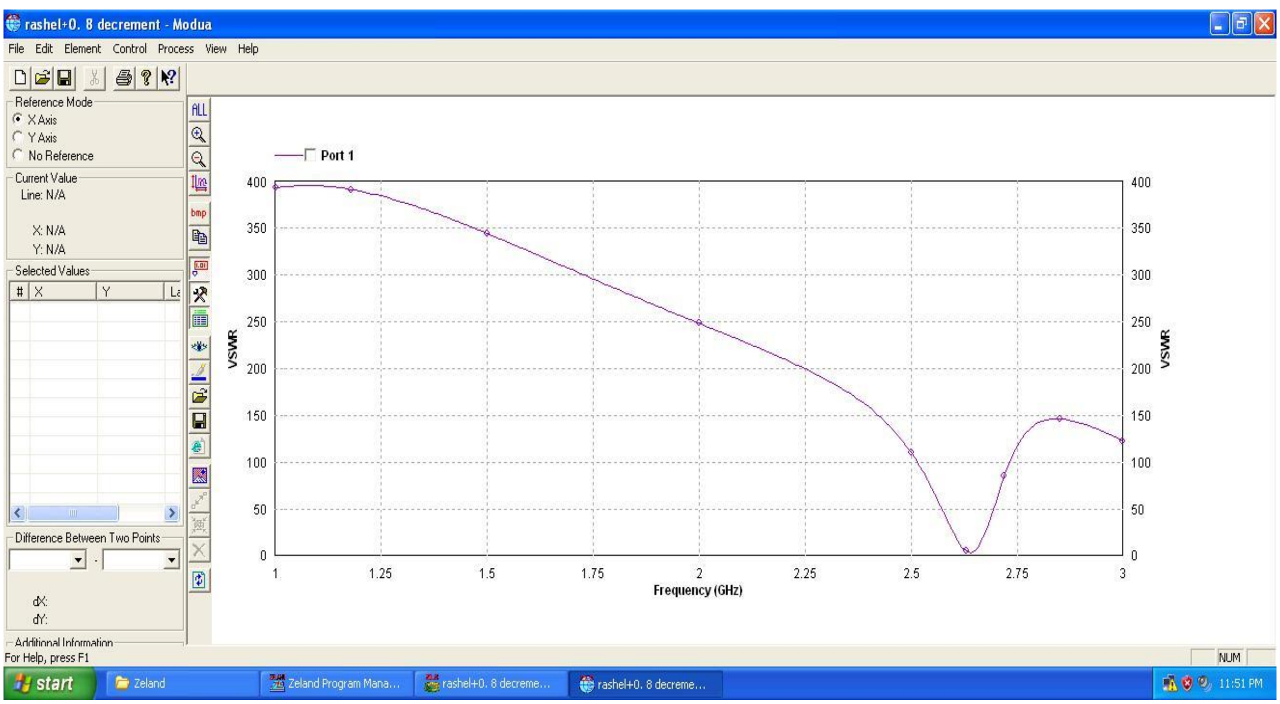


Figure 4.9: *VSWR decreasing the dimension by 20%*

when we **decreased** the dimension by **10%** the resonant frequency was 2.35GHz

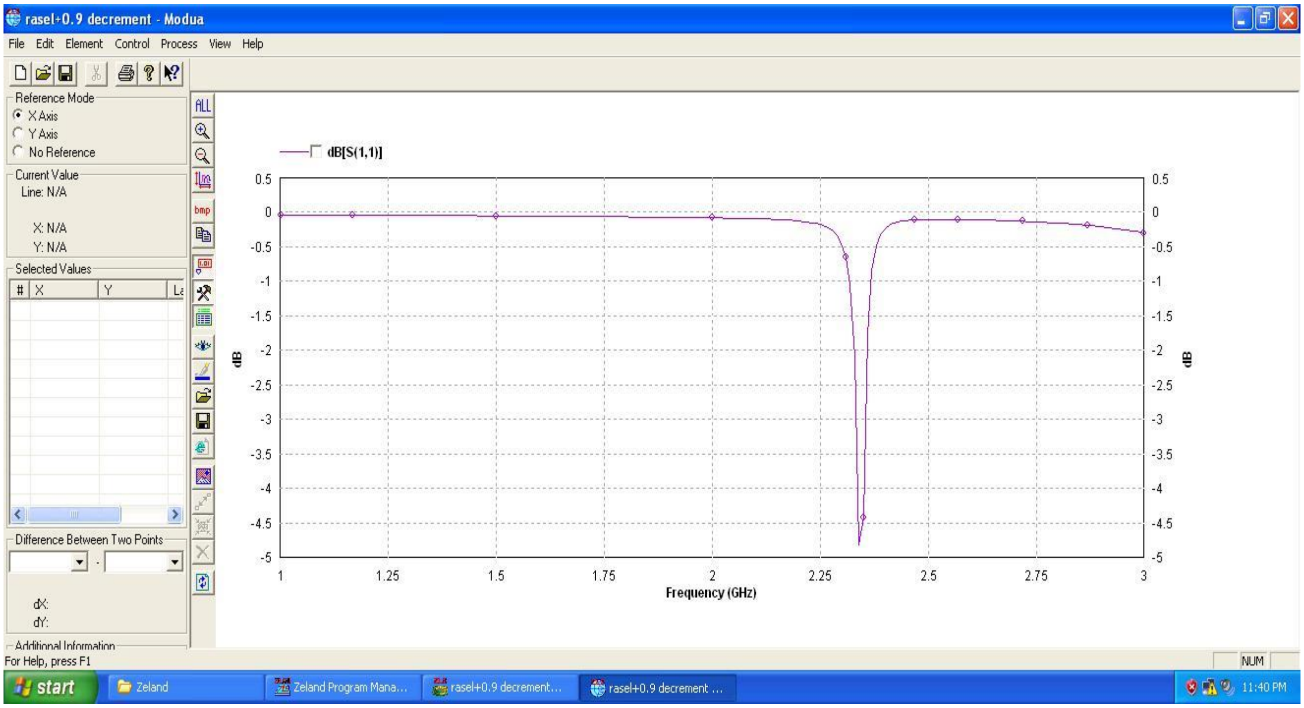


Figure 4.10: : *Figure of dB & phase of s- parameter decreasing the dimension by 10%***.**

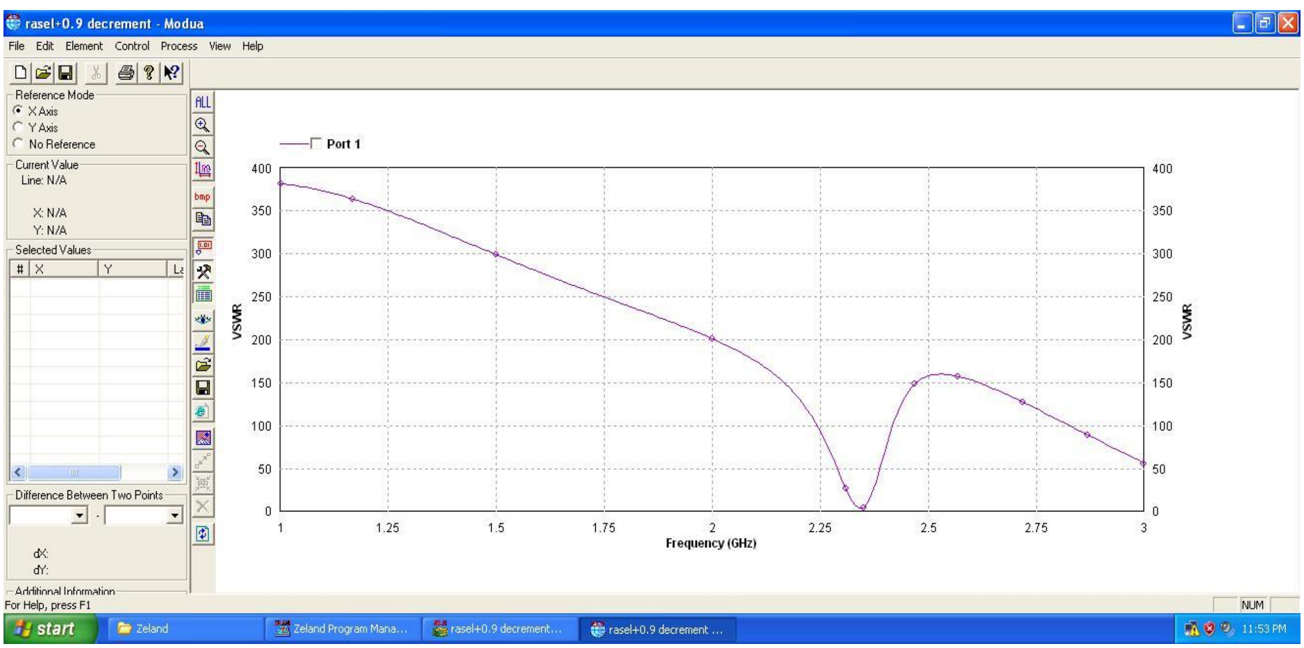


Figure 4.11: *VSWR decreasing the dimension by 10%*

when we **increased** the dimension by **10%** the resonant frequency was 2.6GHz

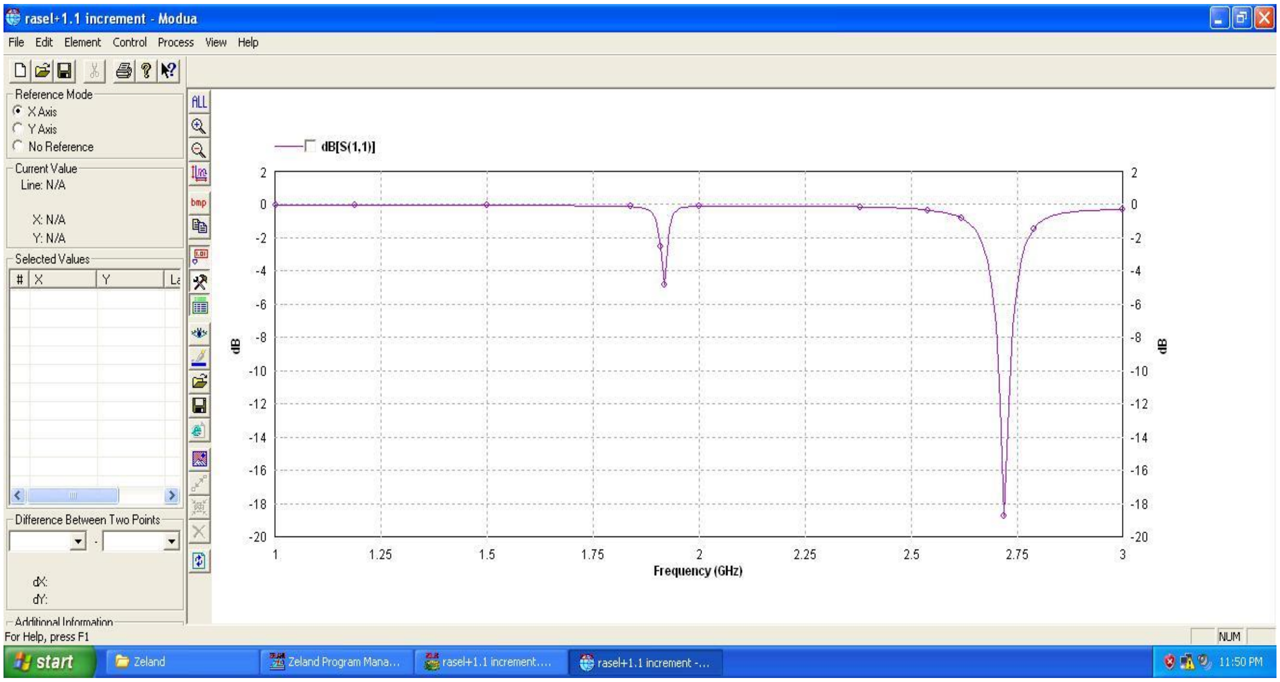


Figure 4.12: *db and s parameters increasing the dimension by 10%***.**

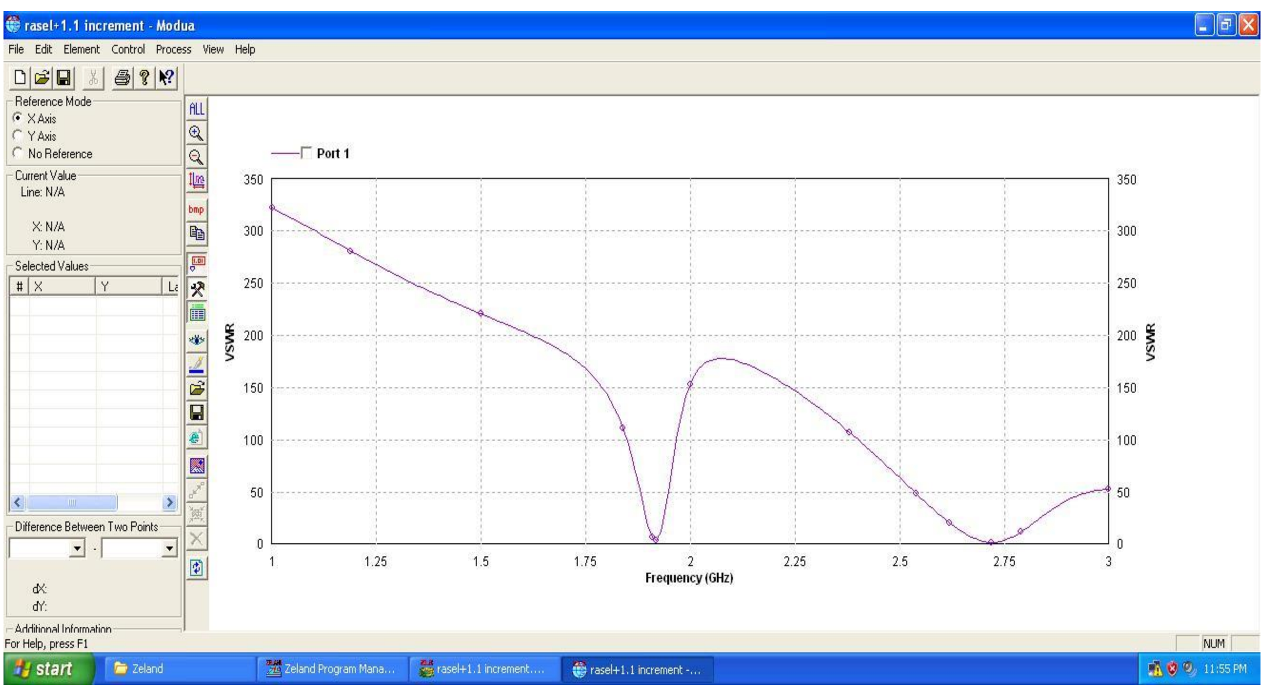


Figure 4.13: *VSWR increasing the dimension by 10%*

when we **increased** the dimension by **20%** the resonant frequency was 2.5GHz

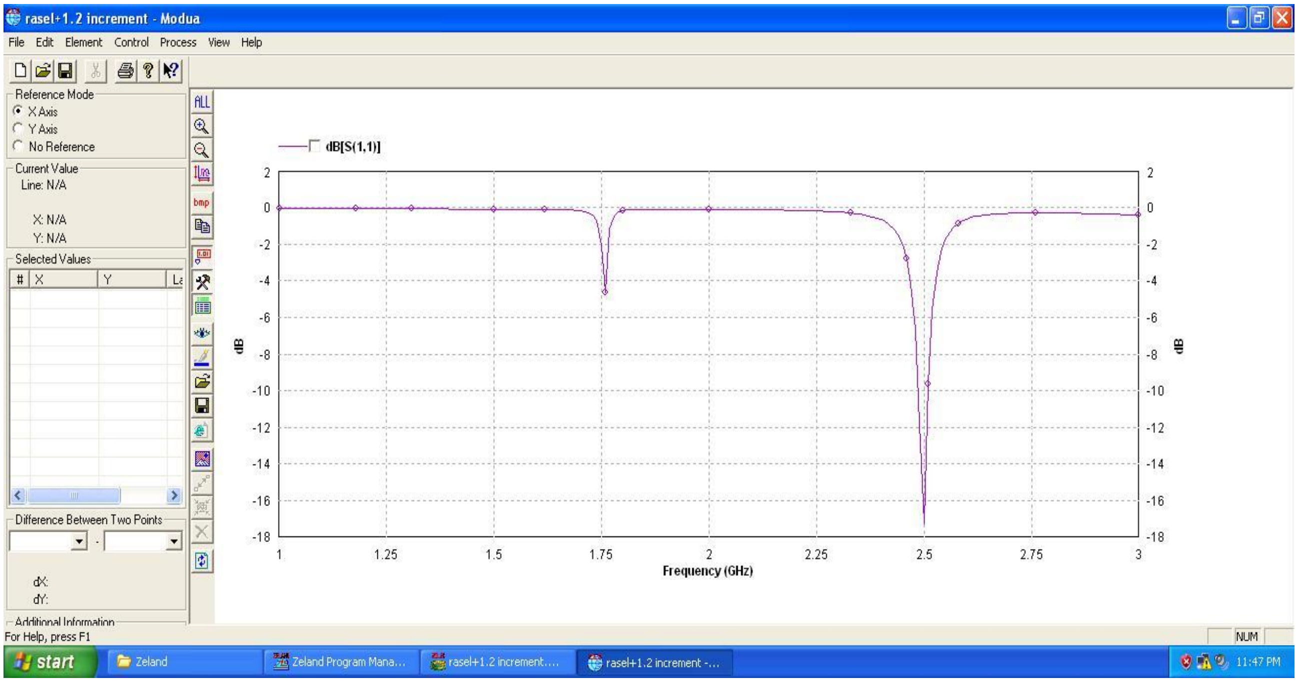


Figure 4.14: *db and s parameters increasing the dimension by 20%***.**

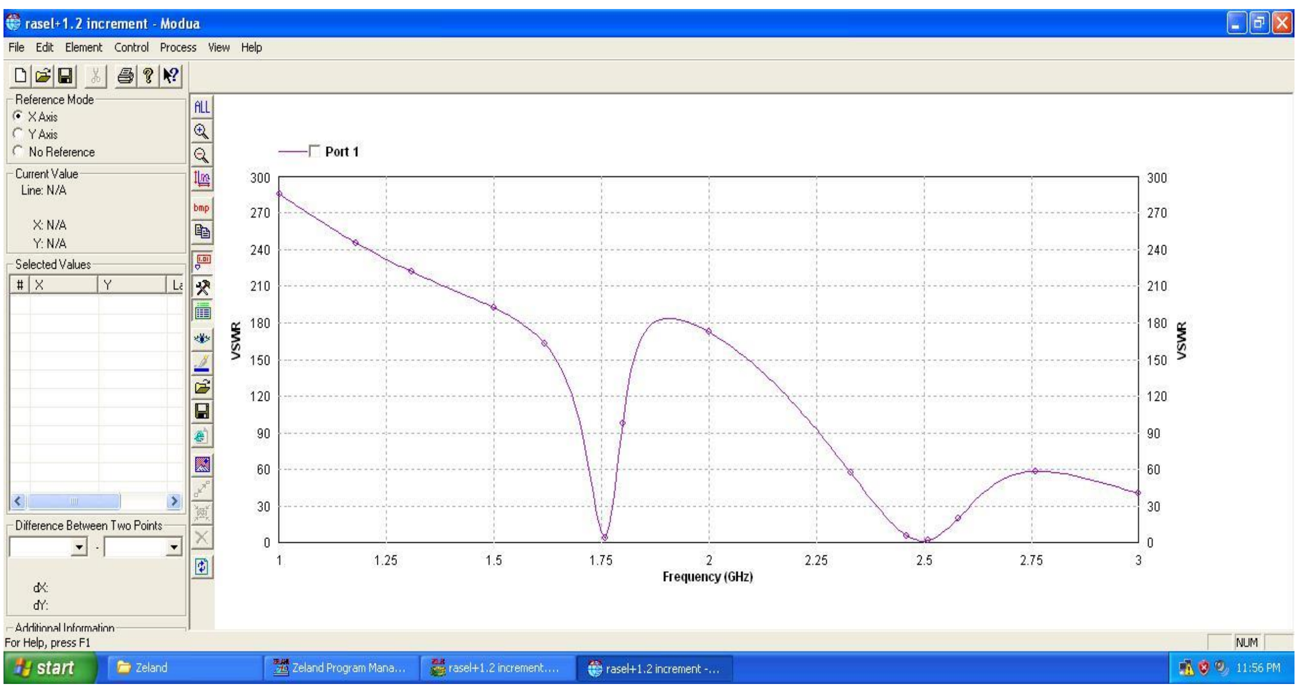


Figure 4.15: *VSWR increasing the dimension by 20%***.**

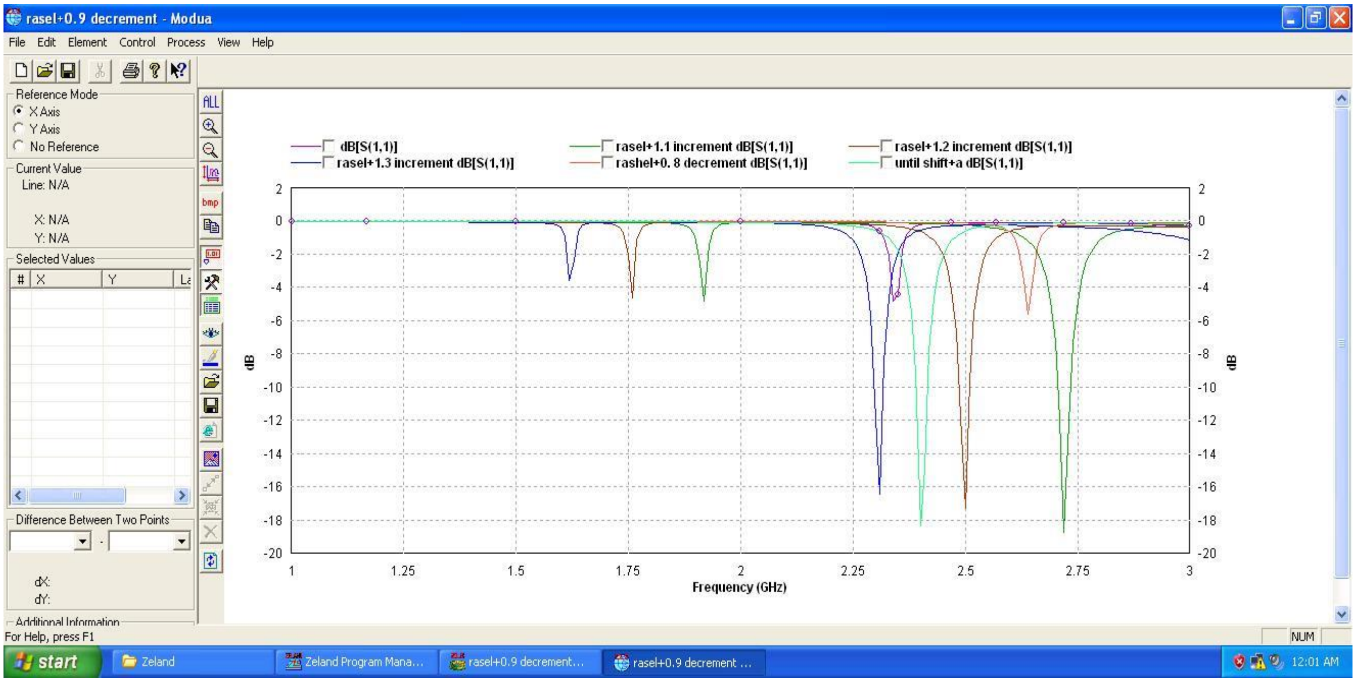


Figure 4.16: *db and s parameters Plotting all the curves in a single figure*

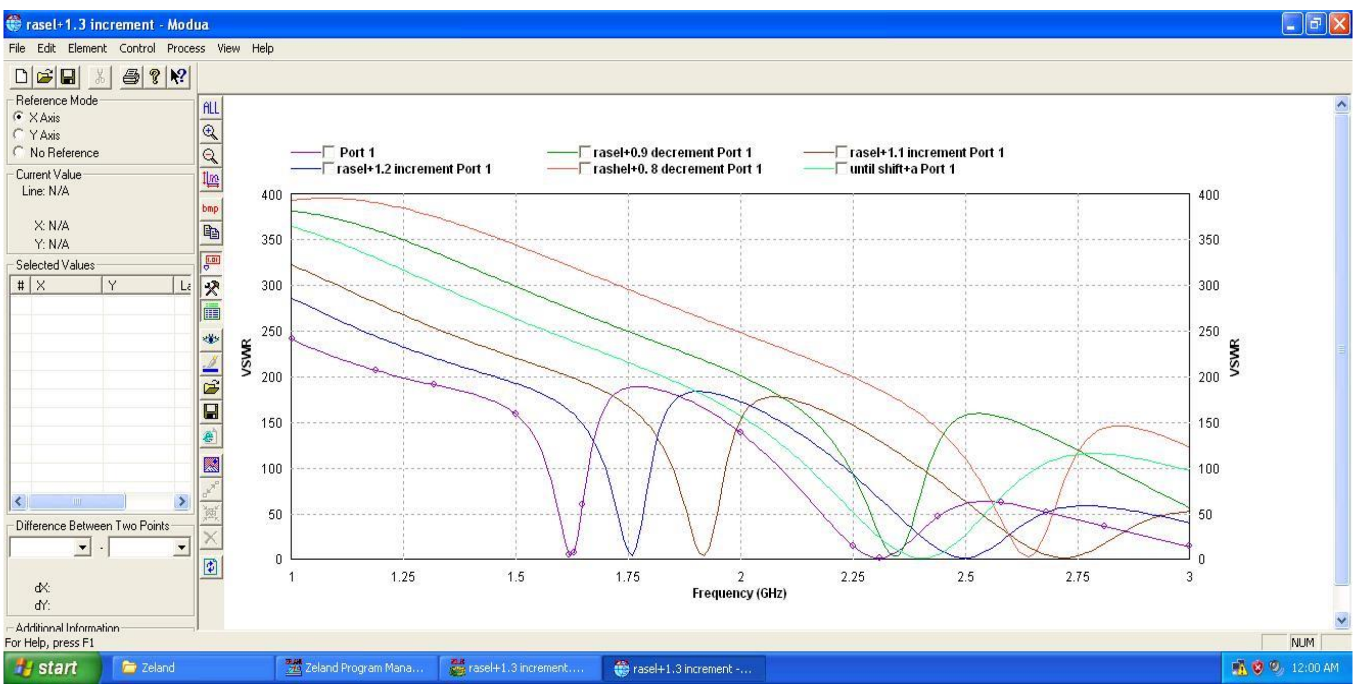


Figure 4.17:*VSWR plotting all the curves in a single figure*

Chapter 5

CONCLUSION AND FUTURE PROSPECTS

Conclusion

Future Prospects

CHAPTER 5

CONCLUSION AND FUTURE PROSPECTS

5.1 CONCLUSION

The optimization of the Microstrip Patch antenna is partially realized that concludes that the change of dimensions of the antenna affects spontaneously and vigorously. So the proper dimensions required for the optimization of 2.4 GHz bandwidth is calculated and determined. With this, the performance of s-parameters and VSWR are checked and evaluated. Realization of results. would be concluded with the fabrication of the patch of the Microstrip Patch Antenna. The investigation has been limited mostly to theoretical study due to lack of distributive computing platform. Detailed experimental studies can be taken up at a later stage to find out a design procedure for balanced amplifying antennas.

5.2 Future Prospects

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

- At present facility for fabrication of patch Antenna is not available in our institute; the same work will be performed later. The simulated, optimized and experimental results will be compared.
- In the near future, we will also work with the Dual Band frequency.
- In future, we also intend to work on different bandwidth.

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