DESIGN OF DUAL BAND SLOTTED RECTANGULAR MICROSTRIP ANTENNAS AND ITS OPTIMIZATION

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CERTIFICATE

This is to certify that the dissertation titled **"Design of Dual Band Slotted Rectangular Microstrip Antennas and its Optimization"** is the bonafide work of Chhagan (2K09/MOC/04) under our guidance and supervision in partial fulfillment of requirement towards the degree of Master of Technology in Microwave and Optical Communication Engineering from Delhi Technological University, New Delhi.

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ABSTRACT

The thesis covers three aspects of Microstrip antenna designs. The first is the analysis and design of single element rectangular Microstrip antenna which operates at the central frequency of 2.4 GHz and the second aspect is the design of dual band rectangular Microstrip antenna which is operates as 2.4 & 3.08 GHz. Both antennas have been modeled, designed and simulated. Basically, transmission line and cavity modeling is going to use to model both antennas. First, the design parameters for single element of rectangular patch antenna have been calculated from the transmission line model equation and extend the antenna design to Dual Band rectangular Microstrip patch antenna using the slots at radiating edge. The simulation process has been done through IE3D electromagnetic software which is based on method of movement (MOM).For rectangular Microstrip antenna design used RT- Duriod which is Teflon based, Microstrip board with dielectric constant 2.4 and the substrate height is 1.58 mm, scaling factor 0.95 and loss tangent is 0.001.

The third is the optimization is done using IE3D simulation software, Using Random Optimization, Powel Optimization, Genetic algorithm optimization and Fast EM Optimization schemes for both single and dual band microstrip antenna.

The properties of antenna such as Return loss and Antenna Bandwidth, Radiation Pattern, Input Impedance, Gain VS. Frequency Plot, S-Parameter has been investigated and compared the results of different optimization schemes and theoretical schemes.

CONTENTS

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List of symbols used

ϵ_r	Dielectric constant of subtract
ϵ_{eff}	effective Dielectric constant of subtract
Ω	Ohm resistance
WLAN	Wireless local area network
VSWR	Voltage standing wave ratio
BW	Bandwidth
Q	Quality factor
S_{11}	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

CHAPTER 1 THESIS OVERVIEW

1.1 Introduction

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 [1]. 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.

Using the Dual Band Microstrip Antenna concept in this thesis dual band rectangular 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 Thesis 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.

Dual-frequency operation of antennas has become a necessity for many applications in recent wireless communication systems, such as GPS, GSM services operating at two different frequency bands. In satellite communication, antennas with low frequency ratio are very much essential. A dual-frequency patch antenna with an inset feed can produce a dual-frequency response, with both frequencies having the same polarization sense with a low frequency ratio. It is also less sensitive to feed position, which allows the use of an inset planar feed.

While optimizing the antenna parameters, using IE3D, the overlapping problem is most often encountered.

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 Thesis Outline

The outline of this thesis is as follows.

Chapter 2: It presents the basic theory of MSAs, including the basic geometries , feeding method and characteristics of the MSA, the advantages and disadvantages of MSAs, impedance matching, shorting techniques, the methods of analysis used for the MSA design finally The calculations needed to find the dimensions of the conventional MSA using transmission line model are presented in this chapter.

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

Chapter 4: This chapter describes the design of Single Band Rectangular Microstrip patch antenna and simulation result using the IE3D electromagnetic simulation software. the optimization has done using powell optimization & Adaptive EM Optimizer result and theoretical result of Microstrip patch antenna are presented. Comparison of theoretical & optimized result has done.

Chapter 5: In this chapter the Dual Frequency Operation of Microstrip antennas and the concept of dual frequency operation using the slots are described. Finally comparison between the optimization and theoretical results using IE3D.

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

CHAPTER 2 MICROSTRIP ANTENNA

2.1 Microstrip 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. Microstrip antenna was conceived in the 1950s, and then extensive investigations of the patch antennas followed in the 1970s and resulted in many useful design configurations. 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

As shown in Figure 2.1, conventional 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 band widths. In most practical applications, patch antenna is rectangular or circular in shape; however, in general, any geometry is possible.

Conventional patch designs yield few percent band widths. In most practical applications, patch antenna is rectangular or circular in shape; however, in general, any geometry is possible. Microstrip antenna should be designed so that its maximum wave pattern is normal to the patch. This is accomplished by proper choice of mode of excitation beneath the patch. Generally, patch of Microstrip antenna thickness is very thin in the range of $t << \lambda_o$ (λ_o is free space wavelength) and the height h of dielectric material is between $0.003\lambda_o$ < h < $0.05\lambda_o$. For a rectangular path, the length L of the element is usually λ_o /3 < L< λ_o /2.

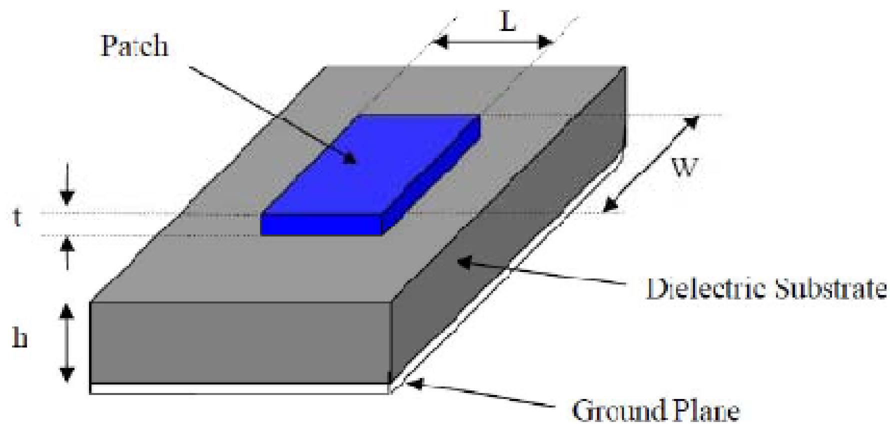


Figure2.1 Rectangular *Microstrip antenna*

There are numerous substrate that can be used for the design of Microstrip antenna, and their dielectric constants are usually in the range of 2.2< ϵ_r < 10, where is relative dielectric constant. The substrate whose size is thick and dielectric constant is in the range of lower end provides better efficiency and bandwidth; but it expenses large element size.

2.3 Feeding Method

There are several techniques available to feed or transmit electromagnetic energy to a microstrip antenna. The four most popular feeding methods are the Microstrip line, coaxial probe, aperture coupling and proximity coupling.

2.3.1 Coaxial Feed

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure 2.2, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane. The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, 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 ($h > 0.02 \lambda o$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems [9]. 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.

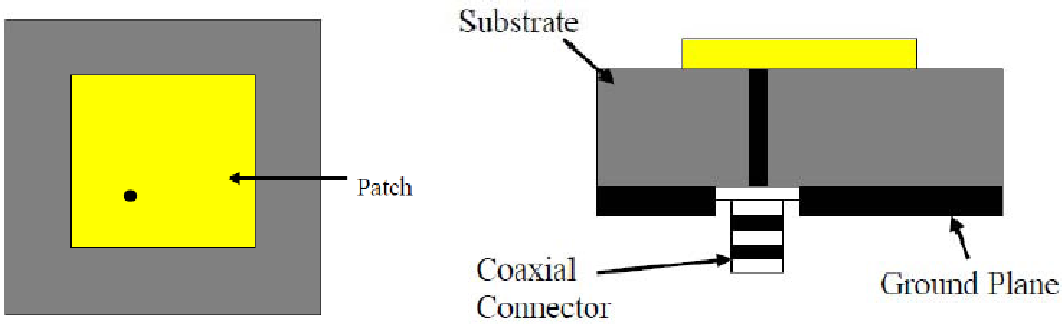


Figure 2.2 Rectangular Microstrip antenna coaxial feed

2.3.2 Microstrip Feed line

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 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 [1]. The feed radiation also leads to undesired cross polarized radiation

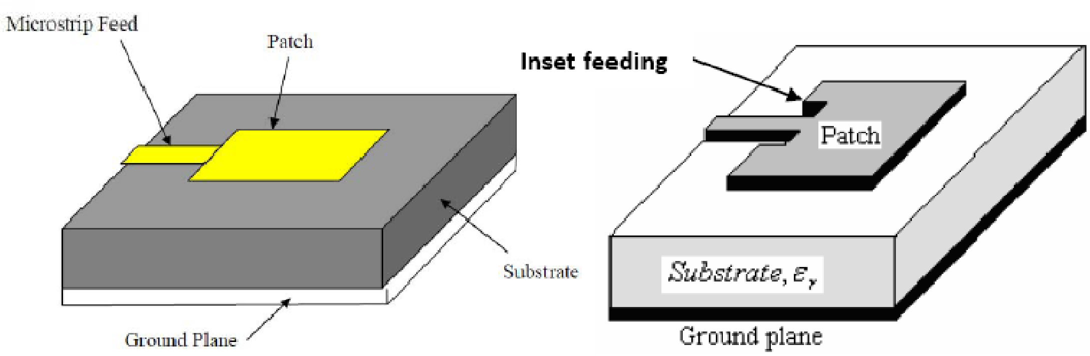


Figure 2.3 Rectangular Microstrip antenna Microstrip line feeding

2.3.3 Aperture Coupled Feed

In this type of feed technique, the radiating patch and the Microstrip feed line are separated by the ground plane as shown in Figure 2.4. 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 [1]. 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 (up to 21%).

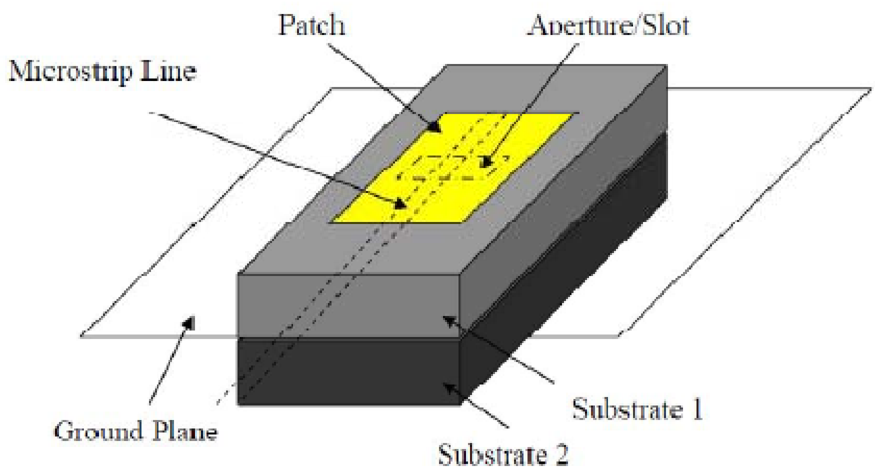


Figure 2.4 Rectangular Microstrip Antenna Aperture coupled feed

2.3.4 Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 2.5, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%) [1], 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.

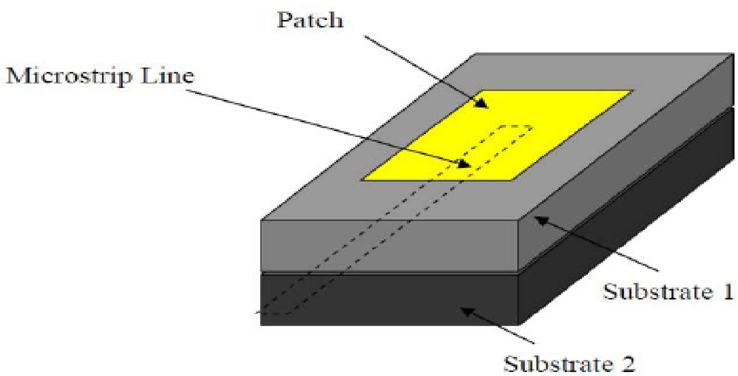


Figure 2.5 Rectangular Microstrip antenna proximity coupled feed

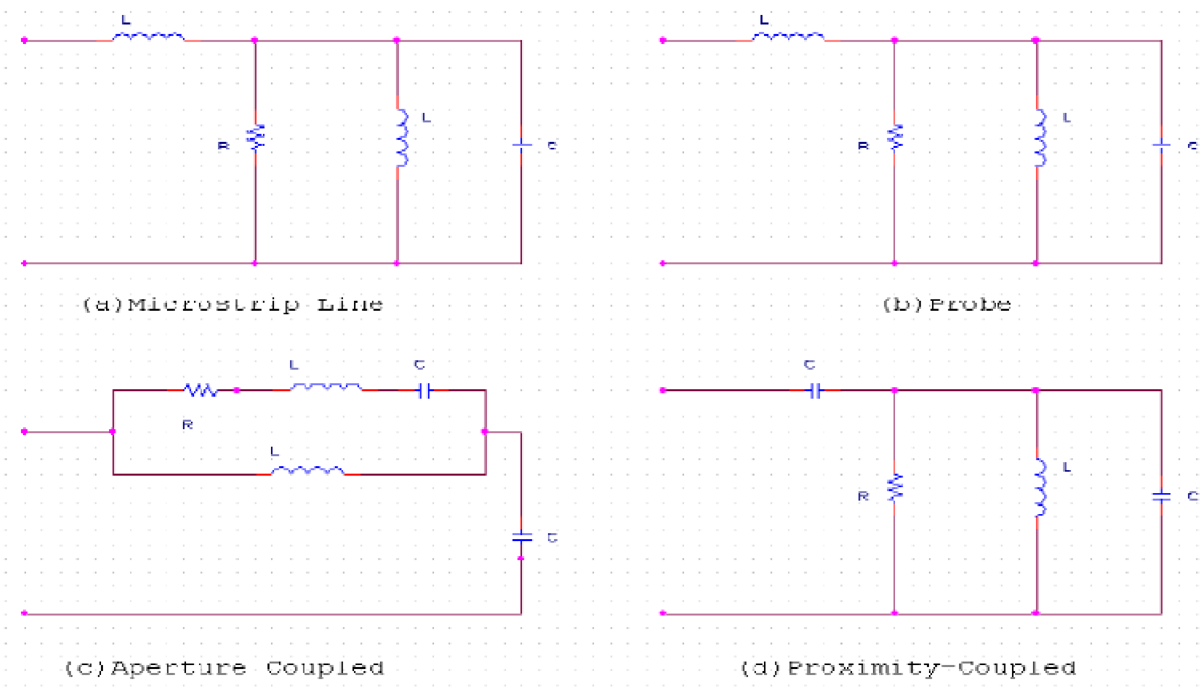


Figure 2.6 Equivalent circuit of typical feeding methods

2.4 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 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.

2.4.1 Transmission line modeling

The transmission line model, as shown in the Figure 2.4, represents the microstrip antenna by two slots, separated by susceptance B and conductance G of length L patch. Due to the dimensions of the patch are finite (or shorter than the base plate) along in length and width, the fields at the edges of the patch undergo fringing. The fringing fields act to extend the effective length of the patch. Thus, the length of a half-wave patch is slightly less than a half wavelength in the dielectric material.

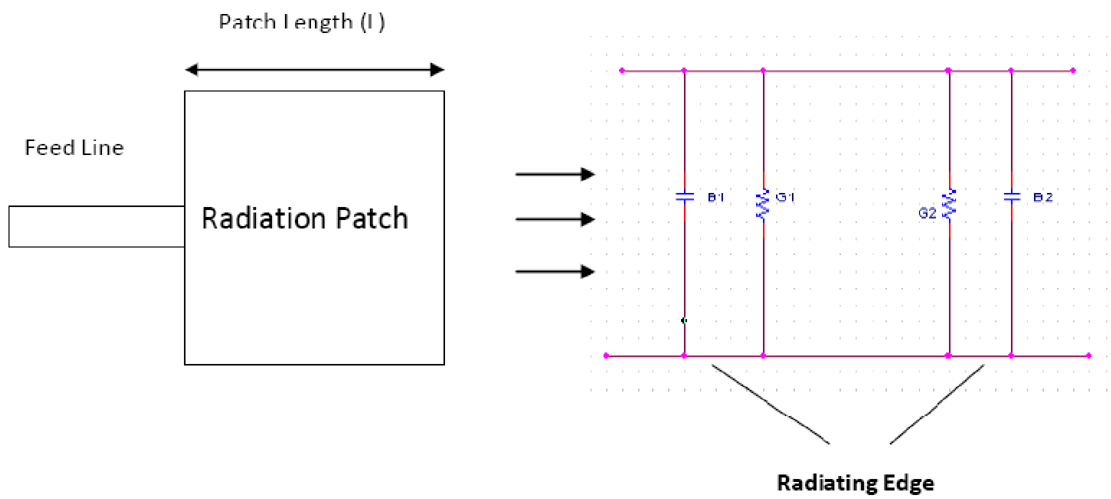


Figure 2.7 Transmission line model

2.4.1.1 Fringing Effect

The amount of fringing of the antenna is a function of the dimensions of the patch and the height of the substrate. Due to fringing electric field lines travels in non-homogeneous material, typically substrate and air, an effective dielectric constant ϵ_r is introduced. For electric line with air above the substrate, the effective dielectric constant has values in the range of $1 < \epsilon_{reff} < \epsilon_r$ The dielectric constant for most applications is much greater than unity.

The effective dielectric constant is expressed by the function of frequency. As the frequency of operation increases, most of the electric field concentrates in the substrate, and therefore, the micro strip behaves more like a homogeneous electric line of one dielectric, and the effective dielectric constant approaches the value of one dielectric constant of the substrate. Experimental results of the effective dielectric constant for micro strip with three different substrates are shown in Figure 2.8

Generally, the relationship of width (W) height (h) effective dielectric constant, and relative dielectric constant of the substrate are related as follow [4][15]

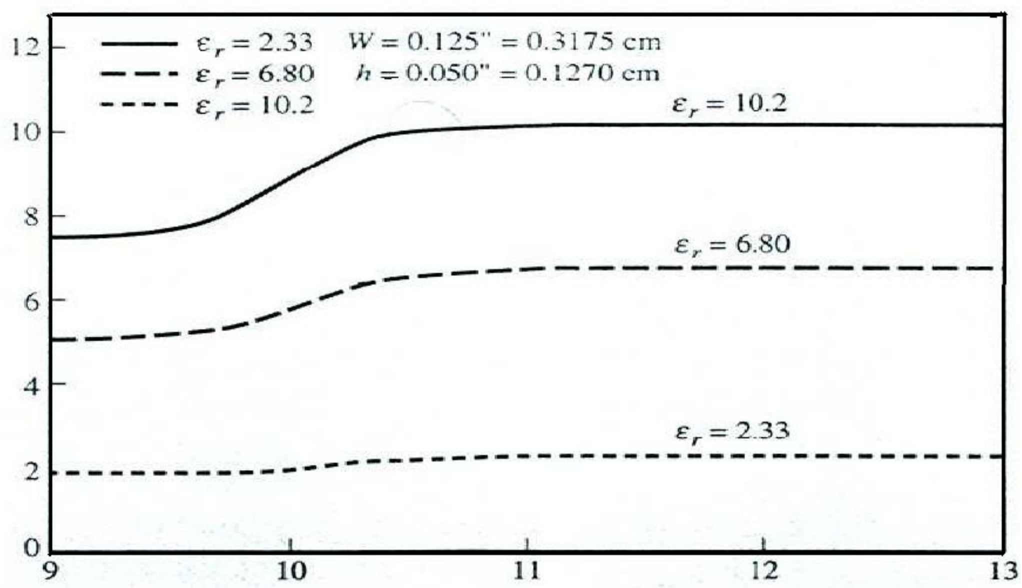
$$\varepsilon_r = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\frac{1}{\sqrt{1 + 12\left(\frac{h}{W}\right)}}\right] \tag{2.1}$$

ϵ_{eff}

Effective

Dielectric

Constant



Log frequency

Figure 2.8 Effective dielectric constant versus frequency for typical substrates

A very popular and practical approximation relation for normalized extension of the length is obtained from below equation. [5][15].

$$\Delta L = 0.4212h\frac{(\varepsilon_r + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_r + 0.3)(\frac{W}{h} + 8)} \tag{2.2}$$

Substrate thickness should be chosen as large as possible to maximize bandwidth, but not so large to minimize the risk of surface wave excitation. The substrate should also has low dielectric constant in order to achieve high efficiency.

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

$$L_{eff} = L + 2\Delta L \qquad (2.3)$$

After analyzing and determining the physical nature of the Microstrip antenna with reference of resonant frequency, f_r , relative dielectric constant, ε_r , height of the substrate h; it is possible to design rectangular microstrip antenna dimension, width *W* and Length *L* , of patch as follow. [6]

$$W = \frac{\lambda_0}{2}((\varepsilon_r + 1)/2)^{-\frac{1}{2}} \qquad (2.4)$$

$$L = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}\sqrt{\varepsilon_{eff}}} - 2\Delta L \qquad (2.5)$$

2.4.1.2 Resonant Input Resistance

As shown in figure 2.4, a Microstrip antenna is represented by an equivalent circuit with two slots having conductance, G, and susceptance, B. The total admittance at slot one (input admittance) is obtained by transferring the admittance of slot two from the output terminal to input terminals using the admittance transformation equation of transmission lines. Ideally two slots are separated by λ /2 where λ is the wavelength in the dielectric (substrate). However, because of the fringing the length of the patch is electrically longer than the actual length. Therefore the actual separation of the two slots is slightly less than λ/2. If the reduction of the length is properly chosen using equation 2.2, the transformed admittance of the slot two becomes.

$$Y_1 = Y_2 \qquad G_1 = G_2 \quad B_1 = -B_2 \qquad (2.6)$$

Therefore the total resonant input admittance is real and is given by:-

$Y_{in}=Y_1+Y_2=2G_1$ (2.7)

Since the total input admittance is real, the resonant input impedance is also real.

$$Z_{in}=\frac{1}{Y_{in}}=R_{in}=\frac{1}{2G_1} \tag{2.8}$$

Considering the mutual effects between the slots, the above equation will be modified as [13]

$$R_{in}=\frac{1}{2(G_1 \pm G_{12})} \tag{2.9}$$

Where the plus (+) sign is used for modes with odd (anti-symmetric) resonant voltage distribution beneath the patch and the slots while minus (-) sign is used for modes with even (symmetric) resonant voltage distribution.

However, the mutual conductance of Micro strip antenna is defined as [1]

$$G_{12}=\frac{1}{|V_0|}\operatorname{Re}\iint_s E_1 x H_2 .ds \tag{2.10}$$

Where E_1 is the electric field radiated by slot one, H_2 is the magnetic field radiated by slot two, V0 is the voltage across the slot.

The equation (2.12) considers the effect of magnetic field radiated by slot two over slot one of the equivalent circuit of micro strip antenna. The integration is performed over the sphere of large radius.

Hence, G_{12} can also be calculated using [14]

$$G_{12}=\frac{1}{120\pi^2}\int_0^{\pi}\left[\sin\left[\frac{k_0 w\cos\theta}{2}\right]/\cos\theta\right]^2 j_0\left(k_0 L\sin\theta\right)\sin^3\theta d\theta \tag{2.11}$$

Where J_0 is the Bessel function of the first kind of order zero and K_0 is a wave number

However, the conductance, G_1, is obtained from radiated power expression: [1]

$$G_{12} = \frac{2P_{rad}}{|V|^2} \tag{2.12}$$

Where P_{ead} is the radiated power of Micro strip antenna [1] given as

$$P_{rad} = \frac{|V_0|^2}{2\pi\eta_o}\int_0^{\pi}\left[\sin\left[\frac{k_0 w\cos\theta}{2}\right]/\cos\theta\right]^2 \sin^3\theta d\theta \tag{2.13}$$

Therefore the conductance can be expressed as

$$G_1 = \frac{I_1}{120\pi^2} \tag{2.14}$$

Where

$$I_1 = \int_0^{\pi}\left[\sin\left[\frac{k_0 w\cos\theta}{2}\right]/\cos\theta\right]^2 \sin^3\theta d\theta \tag{2.15a}$$

The approximated result of equation 2.15.a is [1]

$$I_1 = -2 + \cos(X) + XS_i(X) + \frac{\sin(X)}{X}$$

(2.15b)

$$X = k_0 W \tag{2.15c}$$

And hence, asymptotic value of the equation is described by [1]

$$G_1 = \frac{1}{90}\left(\frac{W}{\lambda_0}\right) \tag{2.16}$$

$$G_{12} = \frac{1}{120}\left(\frac{W}{\lambda_0}\right)$$

Graphical representation of equation 2.16 to determine G1 is presented in the Figure 2.6 (A plot of G1 as a function of W/λ_o). It shows that magnitude of conductance of the Micro strip antenna increases linearly as W/λ_o increases.

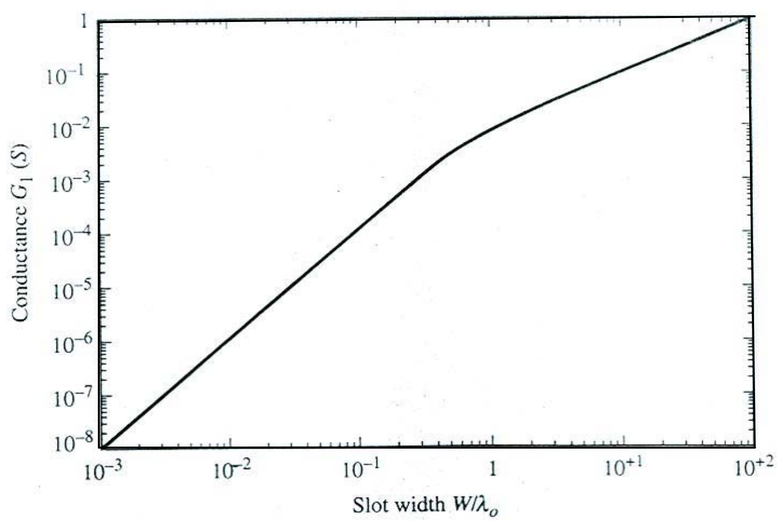


Figure 2.9 Slot conductance as a function of slot width [1]

2.4.1.3 Inset Feed

The resonant input resistance of the Micro strip antenna obtained by equation 2.11 can be changed to appropriate value using inset feed or other alternative technique in order to achieve maximum power transfer.

The inset technique changes the resonant input resistance by introducing a physical notch, as shown in Figure 2.10, which in turn introduces a junction capacitance. The physical notch and its corresponding junction capacitance influence slightly the resonant frequency. The maximum

resonant input resistance value occurs at the edge of the slot (y_0= 0) where the voltage is maximum and current is minimum. However, the minimum resonant input resistance value occurs at the center of the patch (y_0 = L/2). As the inset feed point moves from edge toward the center of the patch the resonant input impedance decreases monotonically and reaches zero at the center When the value of the inset feed-point reaches the center of the patch (y_0 = L/2), the $\cos^2$

(π $y_{0/}$L) function varies very rapidly; therefore the input resistance also changes rapidly with at the position of the feed point.

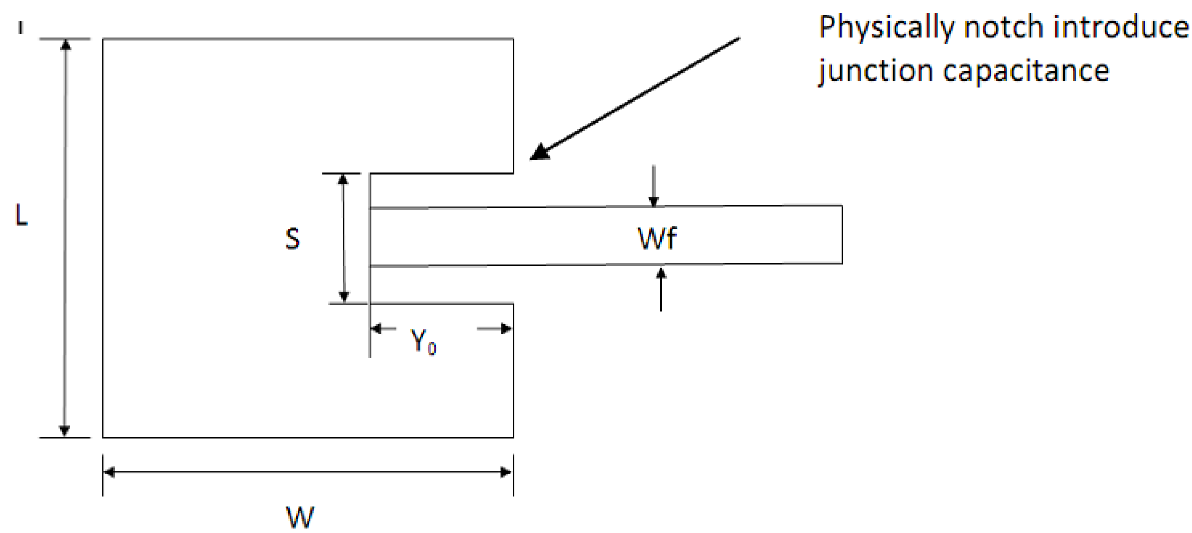


Figure 2.10 (a) Microstrip line inset feeding

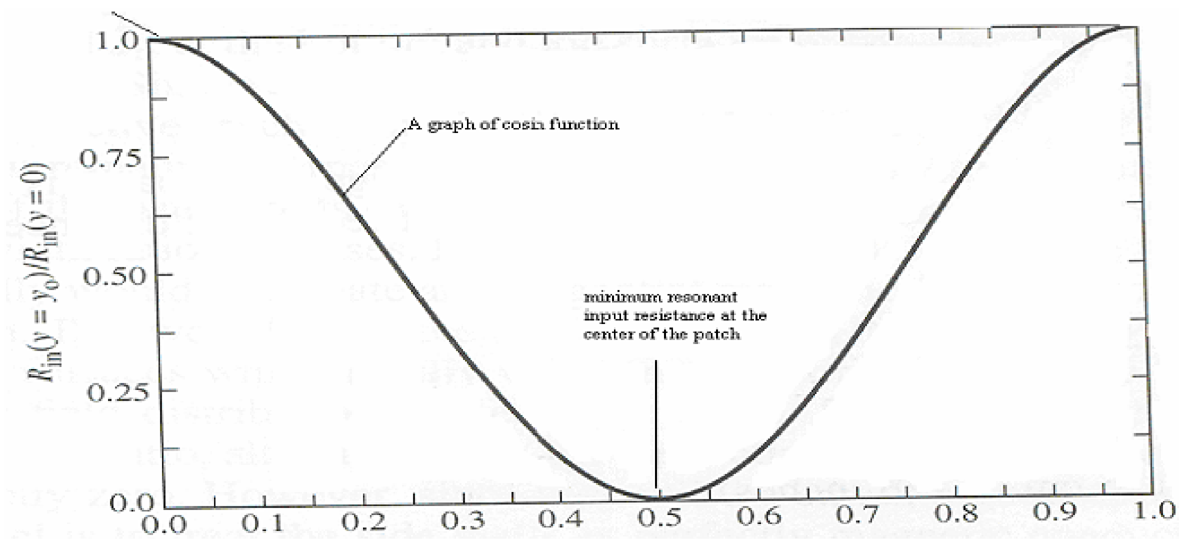


Figure 2.10 (b) variation of normalized input resistance

Analytically, the input resistance for inset feed is given approximately by [1] & [16]

$$R_{in}(y=0)=\frac{1}{G_1 \pm G_{12}}\cos^2\left(\frac{\pi}{L}y_0\right) \tag{2.17}$$

Similarly the characteristics impedance of Microstrip line feed is given by [4]

$$Z_c=\frac{60}{\sqrt{\varepsilon_{reff}}}\ln\left[\frac{8h}{W_0}+\frac{W_0}{4h}\right] \qquad \frac{W_0}{4h}\le 1 \tag{2.18}$$

$$Z_c=\frac{120\pi}{\sqrt{\varepsilon_{reff}}\left[\frac{W_0}{h}+1.393+0.667\ln(\frac{W_0}{h}+1.44)\right]} \qquad \frac{W_0}{4h}\le 1$$

Characteristic impedance of Microstrip line as function w/h is given in Figure 2.11 for common substrates such as RT (2.33), beryllium oxide (6.8) and alumina (10.2). As it is indicated in the Figure 2.11 the characteristic impedance Z_0 is decreased as w/h values increased. For instance, the characteristic impedance 50 ohm is obtained for RT (2.33) dielectric material at the ratio value of w/h of $10^{0.5}$.

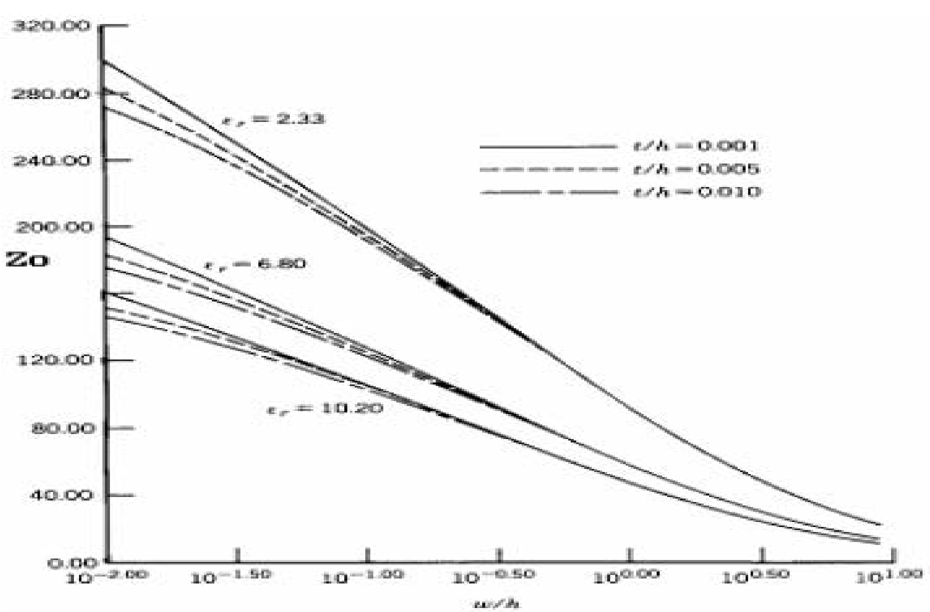


Figure 2.11 Characteristics impedance of Microstrip line as a function of w/h

2.4.2 The Cavity Model

Microstrip antenna resembles dielectric loaded cavities, and exhibit higher order resonances. The normalized fields within the dielectric substrate can be found more accurately by treating that region as a cavity bounded by electric conductors (above and below) and by magnetic wall along the perimeter of the patch. The bases for this assumption are the following points (for height of substrate h << wave length of the field).

The fields in the interior region do not vary with z-axis because the substrate is very thin, $h \ll \lambda$.

The electric field is z-axis directed only, and the magnetic field has only the transverse components in the region bounded by the patch metallization and the ground plane. This observation provides for the electric walls at the top and bottom.

The electric current in the patch has no component normal to the edge of the patch metallization, which implies that the tangential component of magnetic field along the edge is negligible, and a magnetic wall can be placed along the periphery.

This approximation model leads to reactive input impedance, and it does not radiate any power. However, the actual fields can be approximated to the generated field of the model and is possible to analyze radiation pattern, input admittance, and resonant frequency.

2.4.2.1 Current Densities

When the Microstrip antenna (cavity modeled) is energized, charge distribution is established on upper and lower surfaces of the patch, as well as on the surface of the ground plane. The charge distribution is controlled by two mechanisms; attractive and a repulsive mechanism. The attraction is between the corresponding opposite charges on the bottom side of the patch and ground plane, which tends to maintain the charge concentration on the bottom of the patch. The repulsive is between like charges from the bottom of the patch, around its edges, to its top surface as shown in Figure 2.12. The movement of these charges creates corresponding current densities j_b and j_t at the bottom and top of surface of the patch.

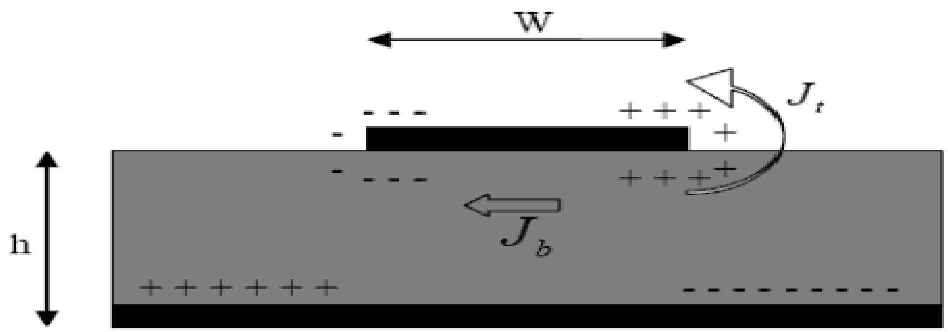


Figure 2.12 charge distribution and current density

Since for the most practical microstrip the height to width ratio is very small, and due to attractive and a repulsive mechanism of charges, only small amount of current flows at the top surface of the patch and large amount of charges are concentrated underneath the patch. The concentration of charges produces current density and at the patch.. However, this flow of current decrease as the height to width ratio increases. It implies that there is no tangential magnetic field component at the edges of the patch. This condition allows a Microstrip antenna to be modeled by a four sided magnetic wall (Figure 2.13) model as shown in Figure 2.13

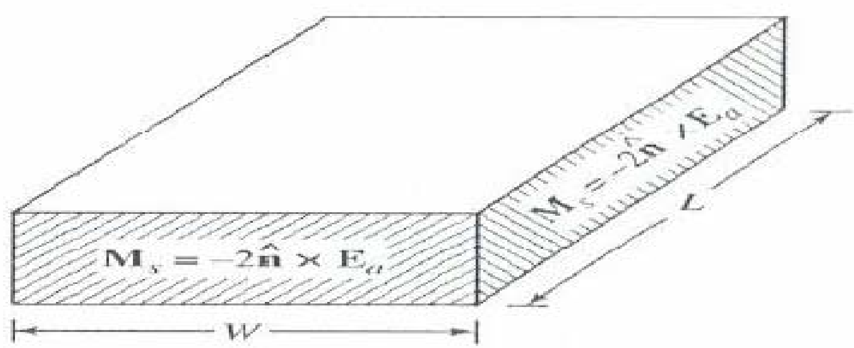


Figure 2.13 Cavity model of rectangular Microstrip antenna

As shown in the Figure 2.13, the four sides slot is represented by the equivalent electric current density and equivalent magnetic current densities, respectively as follows.

J_s= nxH_a and M_s = -nxE_a (2.19)

Where E_a and H_a represent the electric and the magnetic field at the slots.

Considering the presence of the ground plane, the only nonzero current density is the equivalent magnetic current density M_s .

Applying image theory of the magnetic current in the electric ground plane, equivalent magnetic current density M_s is given as

$$M_s = -nxE_a \quad (2.20)$$

Typical E and H plane of Microstrip antenna of two slots with the source of the same magnitude and phase is presented in Figure 2.14.

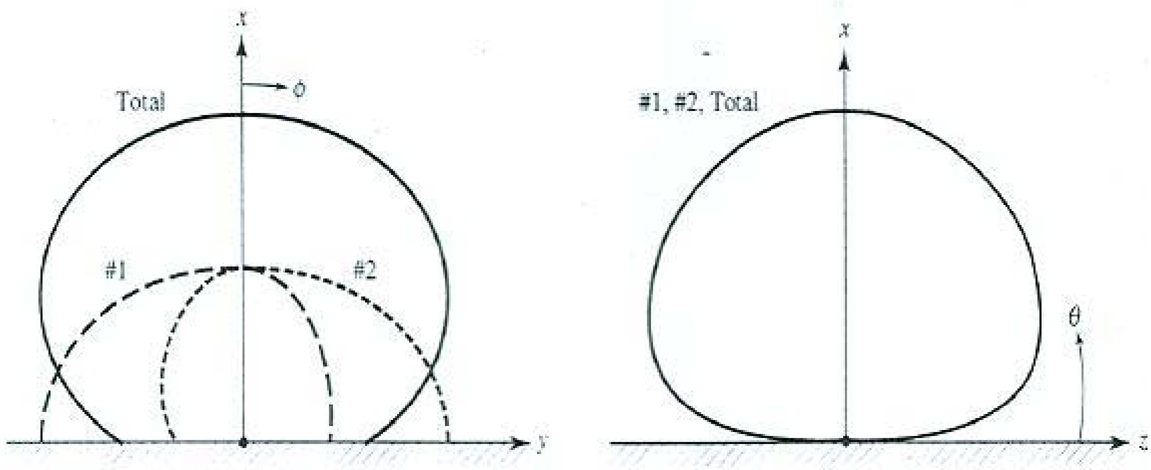


Figure 2.14 Typical E and H plane of micro strip patch antenna

Treating the cavity model as Microstrip antenna is not sufficient to find the absolute amplitude of the electric and magnetic fields. Naturally, the cavity is lossless and requires introducing losses by considering effective loss tangent to behave as an antenna. Because the thickness of the microstrip antenna is usually very small, the waves generated within the dielectric substrate undergo considerable reflections when the fields arrive at the edge of the patch. The electric field is nearly normal to the surface of the patch. Therefore, only TM field configuration is considered within the cavity.

2.4.2.2 Field Configuration

It is common practice in the analysis of electromagnetic boundary-value problems to use auxiliary vector potentials as aids in obtaining solution for electric (**E**) and magnetic (**H**) fields. The most common vector potential functions are the **A**, Magnetic vector potential, and **F**, electric vector potential. These field configurations must be satisfy Maxwell's equations or the wave equation and the appropriate boundary conditions. Transverse magnetic modes, (TM) are field configurations whose magnetic field components lie in a plane that is transverse to the direction of wave propagation. Consider that the wave propagation of the microstrip antenna is to x-axis and hence, magnetic vector potential of cavity model is generally obtained from the homogeneous wave equation [4] & [8].

$$\Delta^2 A_x + k^2 A_x = 0 \tag{2.21}$$

Where $k^2 = \omega^2 \mu \varepsilon$

Since the field expression of TM to a given direction is independent of the other coordinate system, it is sufficient to let the vector potential **A** have only a component in the direction in which the fields are propagated. The remaining components of **A** as well as all of **F** are set equal to zero.

The solution for equation 2.21 is expressed as follow [4]:

$$A_x = [A_1 \cos(k_x x) + B_1 \sin k_x x]\,[A_2 \cos(k_y y) + B_2 \sin k_y y]\,[A_x \cos(k_z z) + B_x \sin k_z z] \tag{2.22}$$

Where, k_x, k_y and k_z are the wave numbers along x, y, z directions, respectively. Its value is determined subject to the boundary conditions.

Considering the boundary condition of the cavity model, H_z $(0<x<h,\ y=0,\ 0<z<W) = 0$ and H_z $(0<x<h,\ y=L, 0<z<W)=0$, the vector potential is described as

$$A_x = A_{mnp} \cos(k_x x') \cos(k_{y} y') \cos(k_z z') \tag{2.23}$$

Where A_{mnp} represents the amplitude coefficients of each mnp mode.

Resonant frequency determines the dominant mode of cavity operation and it is obtained using the following equations [4] & [1].

1. If L>W>h, the mode with lowest frequency (dominant mode) is and its resonant frequency is:

$$(f_r)_{010} = \frac{1}{2L\sqrt{\mu\varepsilon}} \tag{2.24}$$

2. If L>W>L/2, the mode is and its resonant frequency is:

$$(f_r)_{001} = \frac{1}{2L\sqrt{\mu\varepsilon}} \tag{2.25}$$

3. If L>L/2>W>h, the order of the mode is and its resonant frequency is:

$$(f_r)_{020} = \frac{1}{2L\sqrt{\mu\varepsilon}} \tag{2.26}$$

CHAPTER 3 ANTENNA PARAMETERS

3.1 Gain and directivity

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. The relationship between these units is

$$G_{dBd}G_{dBd} = G_{dBi}G_{dBi} - 2.15\ \text{dBidB} \qquad (3.1)$$

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.

3.2 Antenna Polarization

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.

3.3 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 resonant frequency as shown in Figure 3.1. Typically, the feed reactance is very small, compared to the resonant resistance for thin substrates.

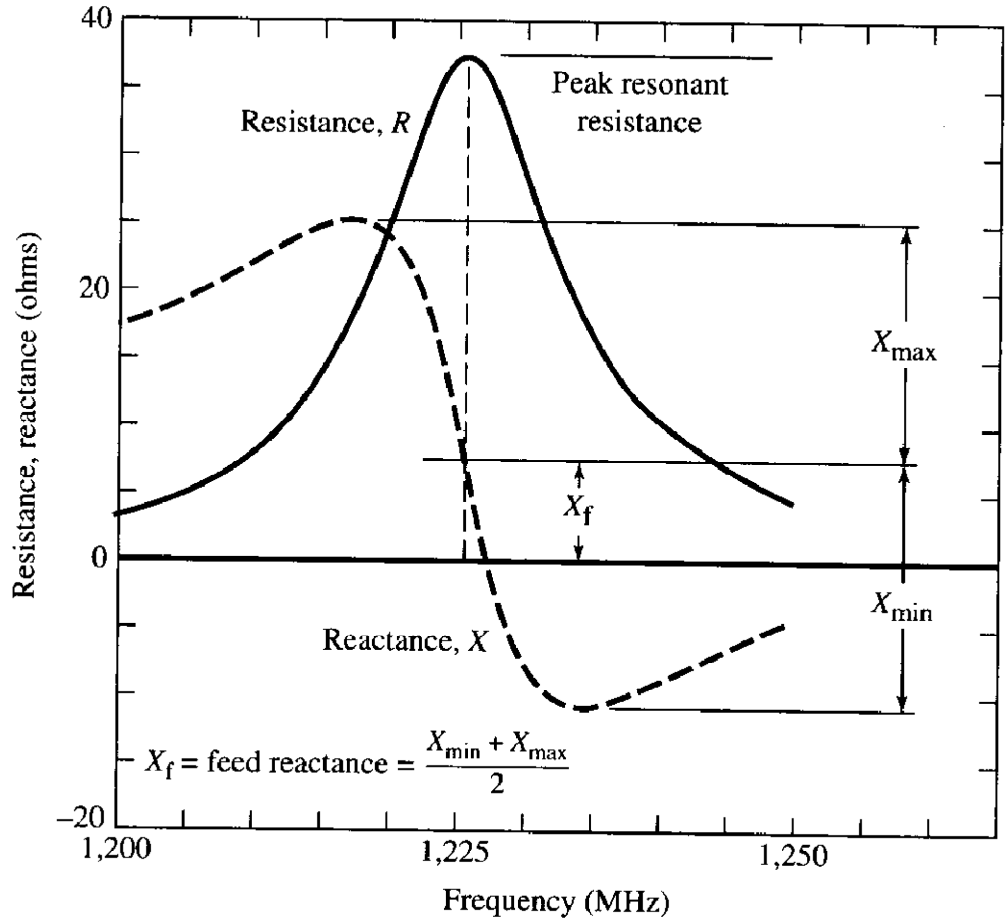


Figure 3.1 *Typical variation of resistance and reactance of rectangular Microstrip antenna versus frequency*

3.4 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.

3.5 Bandwidth

The bandwidth of an antenna is defined as the range of frequency within the performance of the antenna. In other words, characteristics of antenna (gain, radiation pattern, terminal impedance) have acceptable values within the bandwidth limits. For most antennas, gain and radiation pattern do not change as rapidly with frequency as the terminal impedance does. Since the transmission line characteristic impedance hardly changes with frequency, VSWR is a useful, practical way to describe the effects of terminal impedance and to specify an antenna's bandwidth. 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. [1]

3.6 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.

$$\frac{1}{Q_t} = \frac{1}{Q_{rad}} + \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_{sc}} \tag{3.2}$$

Q_t : Total quality of factor

Q_{rad} : Quality factor due to radiation losses

Q_c : Quality factor due to conduction losses

Q_{dm} : Quality factor due to dielectric losses

Q_{sc} : Quality factor due to 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. For very thin substrates $h << \lambda_o$ of arbitrary shapes including rectangular, there approximate formulas to represent the quality factors of the various losses.

These can be expressed as

$$Q_c = h\sqrt{\pi f \mu \sigma} \tag{3.3}$$

$$Q_d = \frac{1}{\tan \delta} \tag{3.4}$$

$$Q_{rad} = \frac{2\omega\epsilon}{hG_t/l} \tag{3.5}$$

Where tan δ is the loss tangent of the substrate material, σ is the conductivity of the conductors associated with the patch and ground plane, Gt/l is the total conductance per unit length of the radiating aperture and k for rectangular microstrip antenna is The as represented by 3.5 is inversely proportional to the height of the substrates. A typical variation of the bandwidth for a Microstrip antenna as a function of the normalized height of the substrate, for two different substrates, is shown in Figure 3.1. 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 (3.6) decreases as normalized height of the substrate increased.

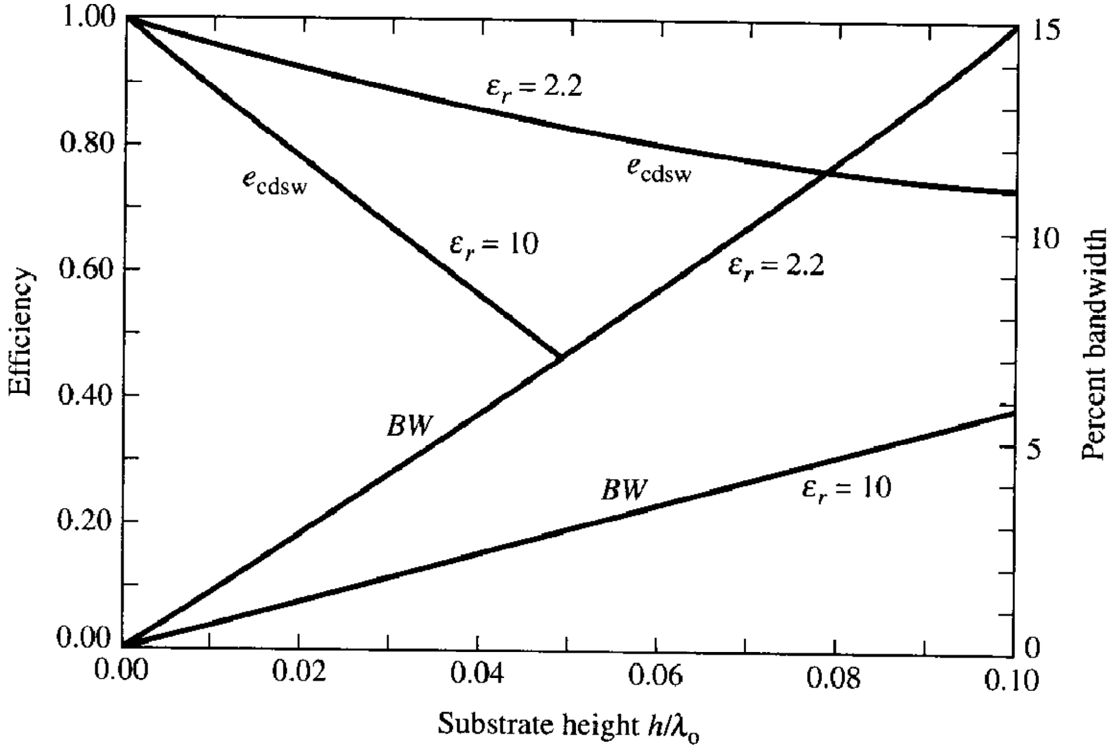


Figure 3.2 Efficiency and bandwidth versus substrate height at constant resonant frequency for Rectangular Microstrip patch for two different substrates

$$\eta = \frac{Q_t}{Q_{rad}} \tag{3.6}$$

CHAPTER 4 SINGLE BAND MICROSTRIP ANTENNA

4.1 Rectangular Microstrip

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. This is we explained in chapter 1 in previous.

4.2 Single Band Microstrip

A single element of rectangular patch antenna, as shown in Figure 4.1, can be designed for the 2.4 GHz resonant frequency using transmission line model taking eqn. 2.4, 2.5, 2.13 and 2.20.

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 =2.4) with dielectric loss tangent of 0.001 is selected as the substrate with 1.58 mm height[7]. 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.

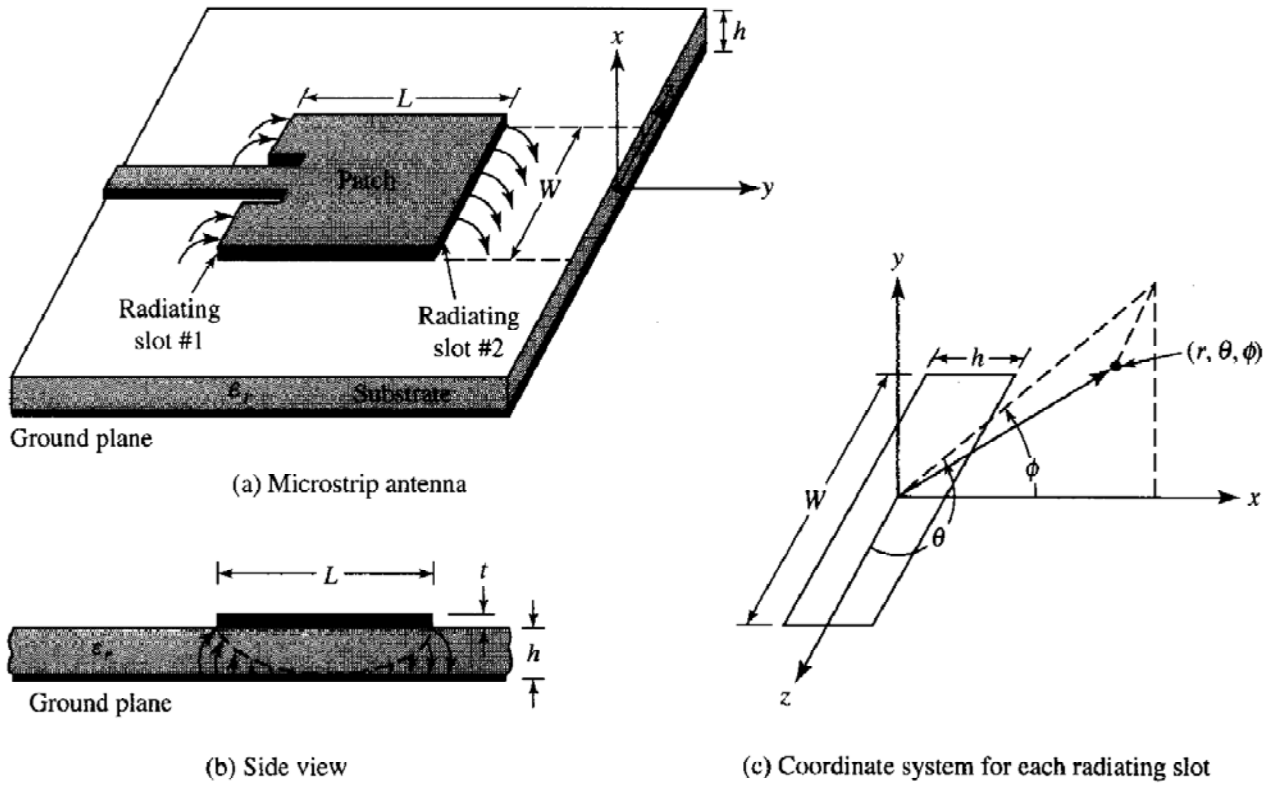


Figure 4.1 Typical Rectangular Patch Antenna

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.

Shapes	Single Band Rectangular
Frequency of operation	2.4 GHz
Dielectric constant of substrate	2.4 (RT Duriod)
Height of the dielectric substrate	1.58 mm
Feeding method	INSET feeding
VSWR	1.5:1
Beam width Azimuth Zenith	 <100 <100
Gain	5 dBi - 8dBi
Polarization	Linear

Table 4.1 Design parameter specifications of microstrip antenna.

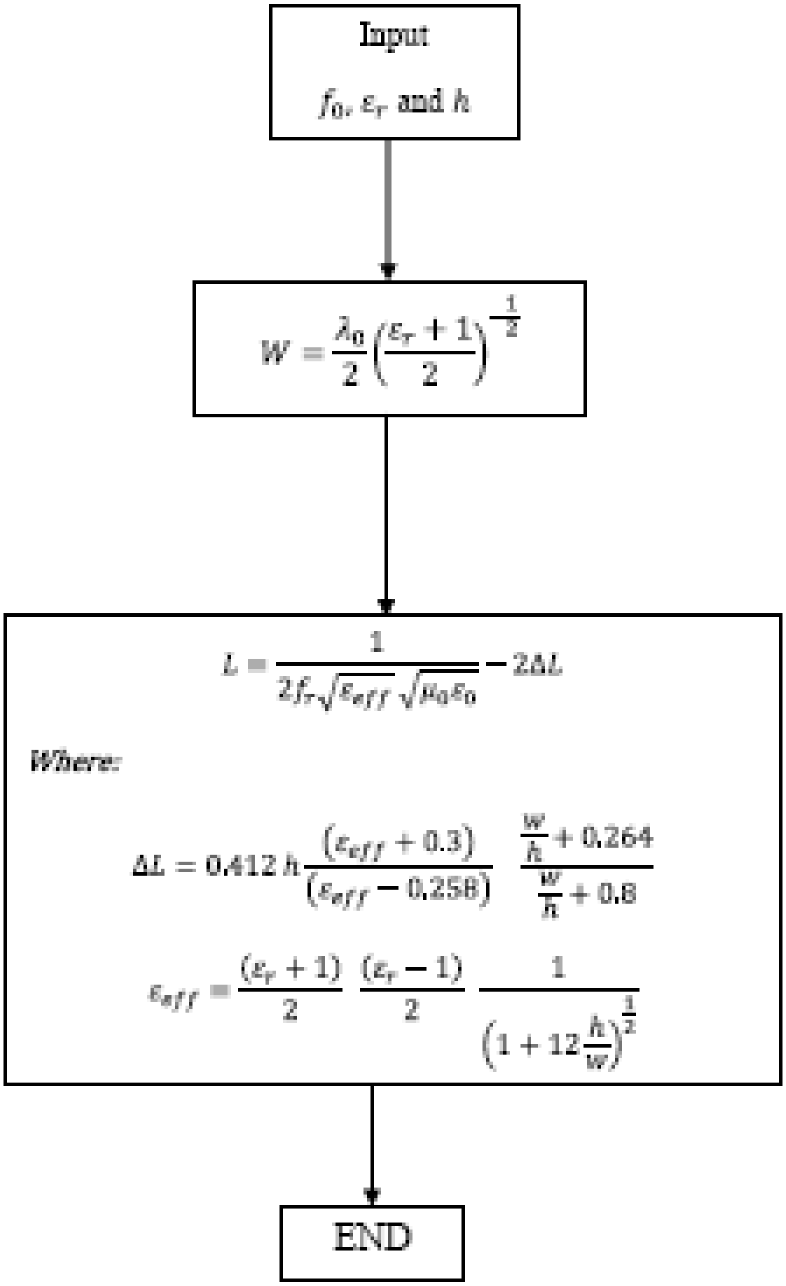


Figure 4.2 Flow chart based on usual design procedure for rectangular patch antenna

Steps required for calculating width (W) and Length (L) of microstrip antenna

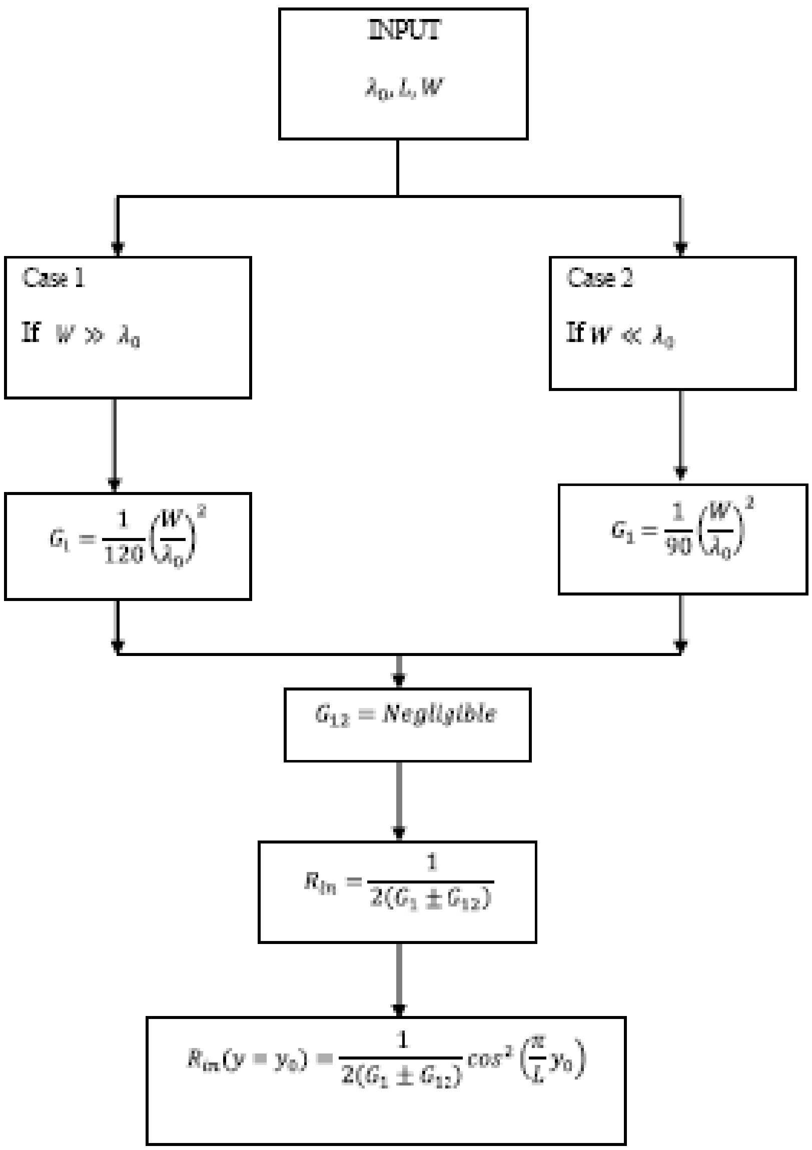
Step 1. Initially, select the desired resonant frequency, thickness and dielectric constant of the substrate.

Step 2. Obtain Width (W) of the patch by inserting ϵ_r and λ_o.

Step 3. Obtain Length (L) of the patch after determining ΔL and ϵ_r .

It is also possible to determine the inset length of the patch to ensure matching from the flow chart (Figure 4.7) taking the resonant wave length λ_o , width W and length L of the patch as input.

Steps required for calculating the inset depth of single band Microstrip patch antenna



Step 1: Consider that L, W of the patch is calculated and is known. (As an input)

Step 2: Depending to magnitude of W greater or less than ; and then determine G1.

Step 3: Assume that G12 is negligible and fined input resistance of the patch.

Step 4: Consider that the characteristic impedance of Microstrip line feeder is 50 ohm. Thus, equate the equation to obtain matching between the input impedance of the patch and feeder. (i.e. inset length, y_o).

Result:

Design of Single Band Microstrip Patch Antenna	
Width of the Patch(W)	46.9 mm
Effective dielectric constant of patch (ϵ_r)	2.2922
Length of the Patch(L)	39.6 mm
Input resistance of the Patch (R_{in})	50Ω
Inset Depth of the Patch (y_o)	13 mm
Width of Microstipline (w_o)	4.2 mm

Table 4.2 Calculated result of single band rectangular microstrip antenna

4.3 Geometry of Proposed Antenna

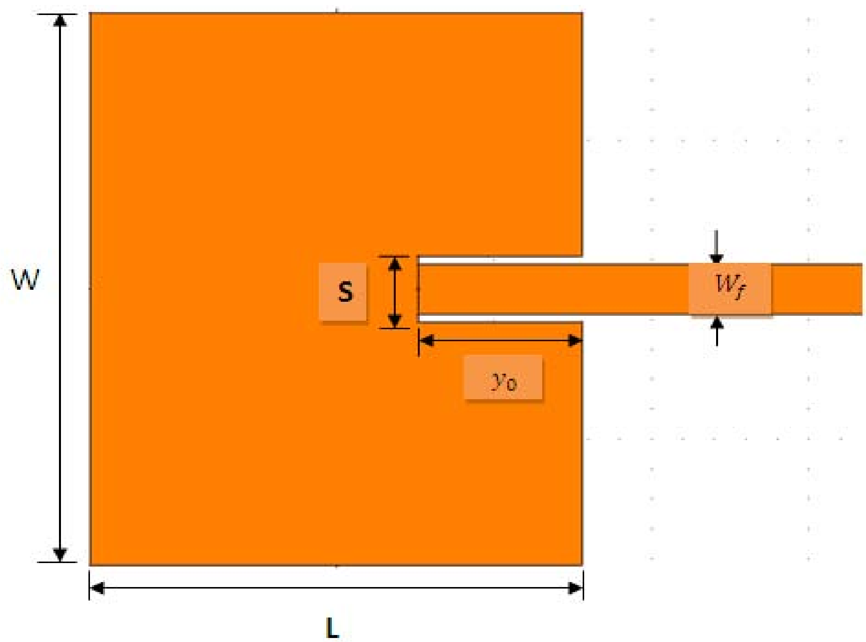


Figure 4.4 Geometry of Single Band Microstrip Antenna

4.4 Simulation Setup and Result

4.4.1 Simulation Setup

The software used to model and simulate the Microstrip patch antenna is Zeland Inc's IE3D. IE3D 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 Return loss plot, VSWR, current distributions, radiation patterns etc. For design simplicity of the conventional MSA, the patch's length and width are shows in the table 4.2.

4.4.2 Return loss and Antenna Bandwidth

The Inset feed used to design the rectangular patch antenna. The center frequency is selected as the one at which the return loss is minimum. As described in chapter two, the bandwidth can be calculated from the return loss (RL) plot. The bandwidth of the antenna is said to be those range of frequencies over which the return loss is greater than 7.3 dB, which is equivalent to 2.5:1 VSWR. The bandwidth of the antenna for this feed point location using IE3D at Adaptive EM Optimizer is seen to be 60-MHz and a center frequency of 2.392 GHz is obtained which is very close to the desired frequency of operation. It was observed from many trials of simulations that as the feed point location is moved away from the edge of the patch, the center frequency starts to decrease. This may be due to the highly sensitive nature of the input impedance bandwidth to position of the probe. Figure 4.3(a), 4.3(b), 4.3(c), 4.3(d), 4.3(e) is respectively the theoretical result, Random Optimization, Powel optimization, Genetic Algorithm Optimization and the Adaptive EM optimization below shows the return loss snap taken during simulation. The return loss (in dB) is plotted as a function frequency.

1. **Theoretical result (IE3D):**

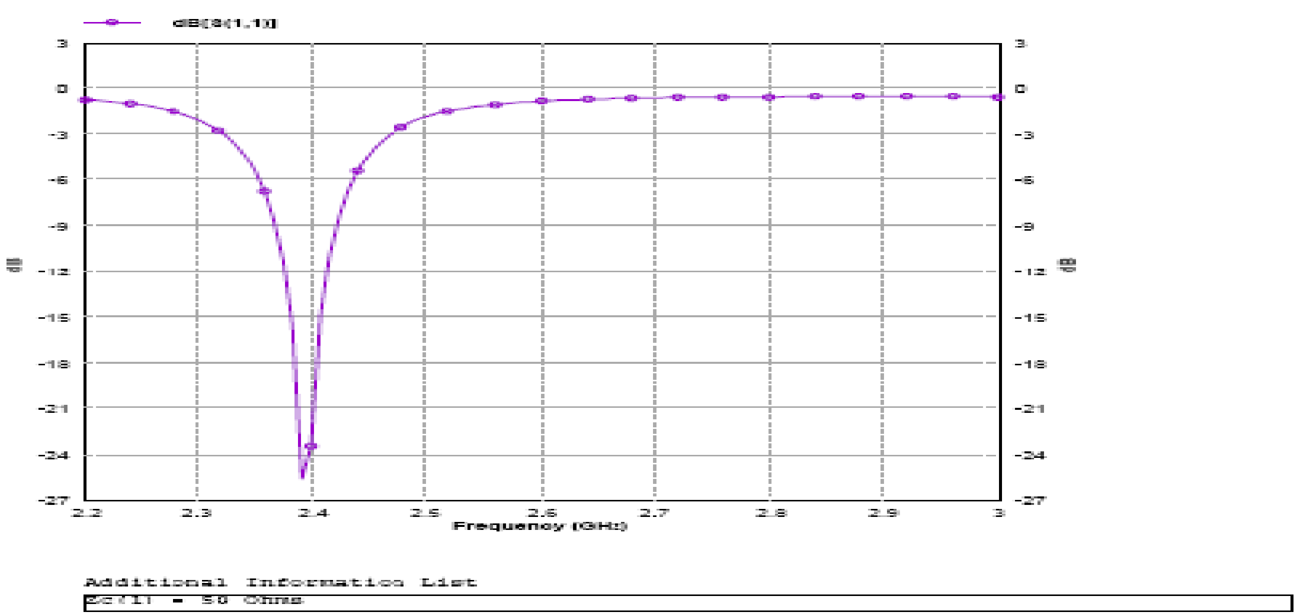


Figure 4.5(a) Return loss is -25.540 (2.392 GHz)

2. Random Optimization:

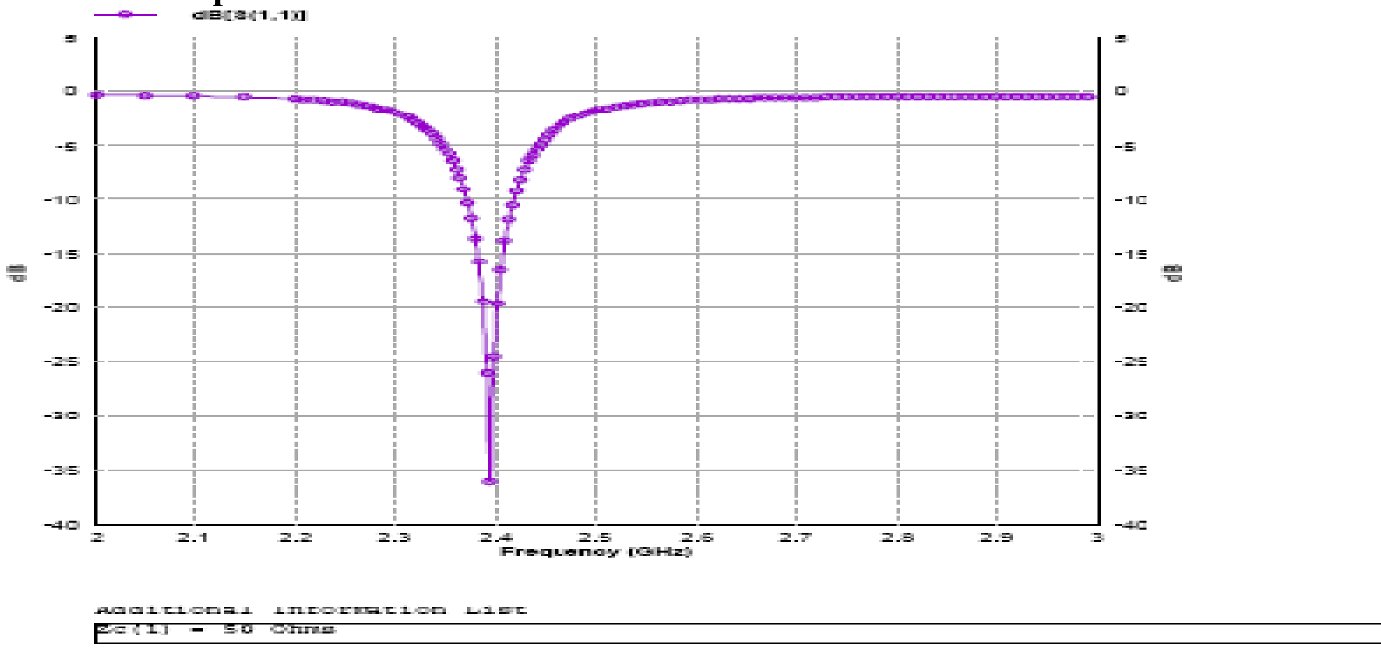


Figure 4.5(b) Return loss is -36.1 (2.956 GHz)

3. Powell Opimization :

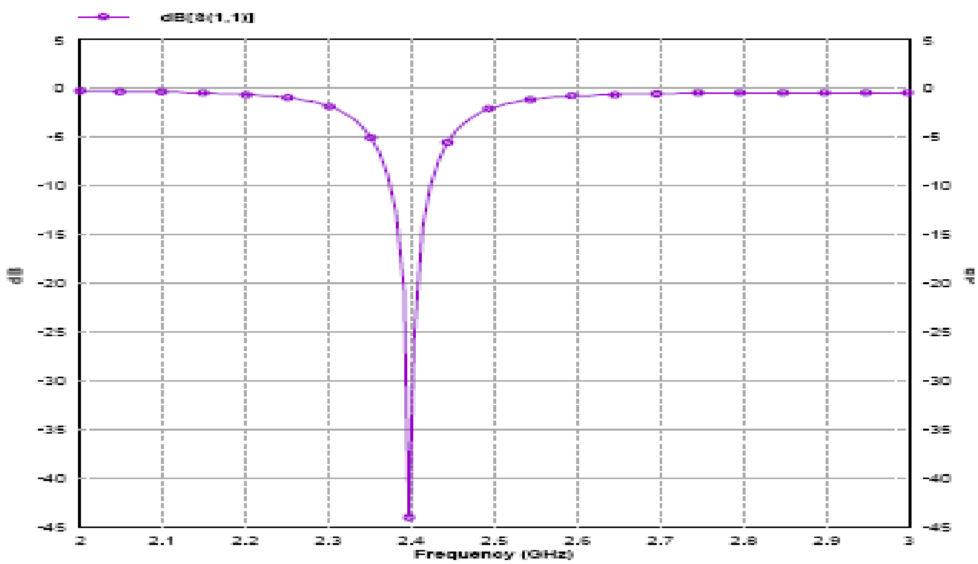


Figure 4.5(c) Return loss is -44.1 (2.4GHz)

4. Genetic Algorithm Optimization:

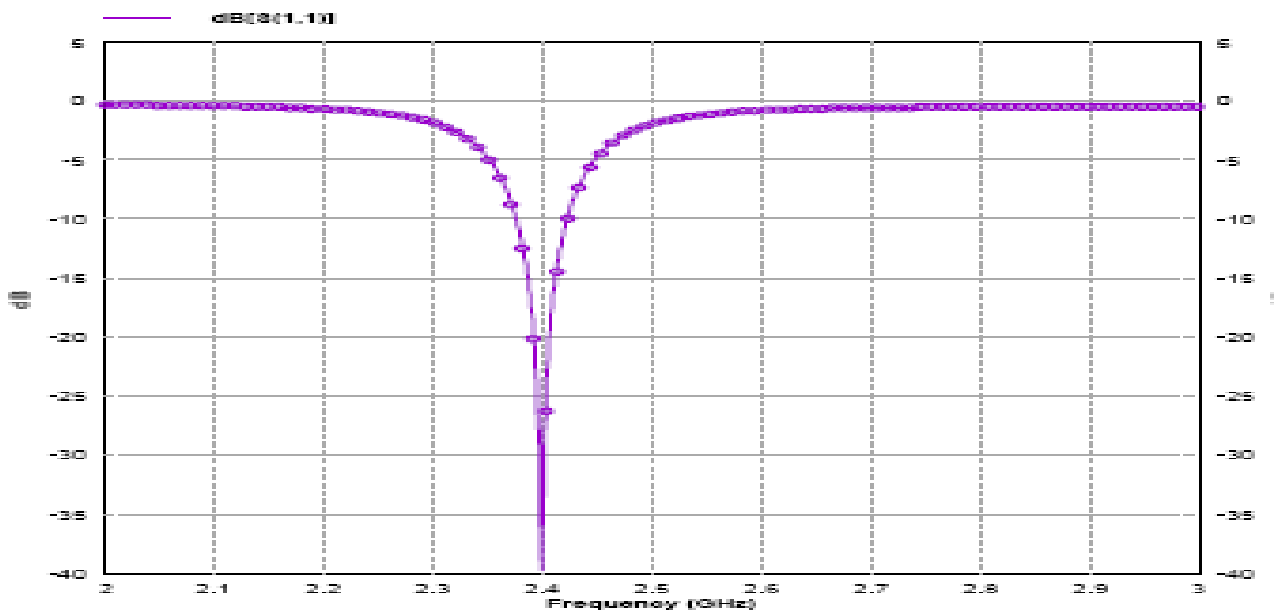


Figure 4.5(d) Return loss is -39.76 (2.4GHz)

5. Adaptive EM Optimizer:

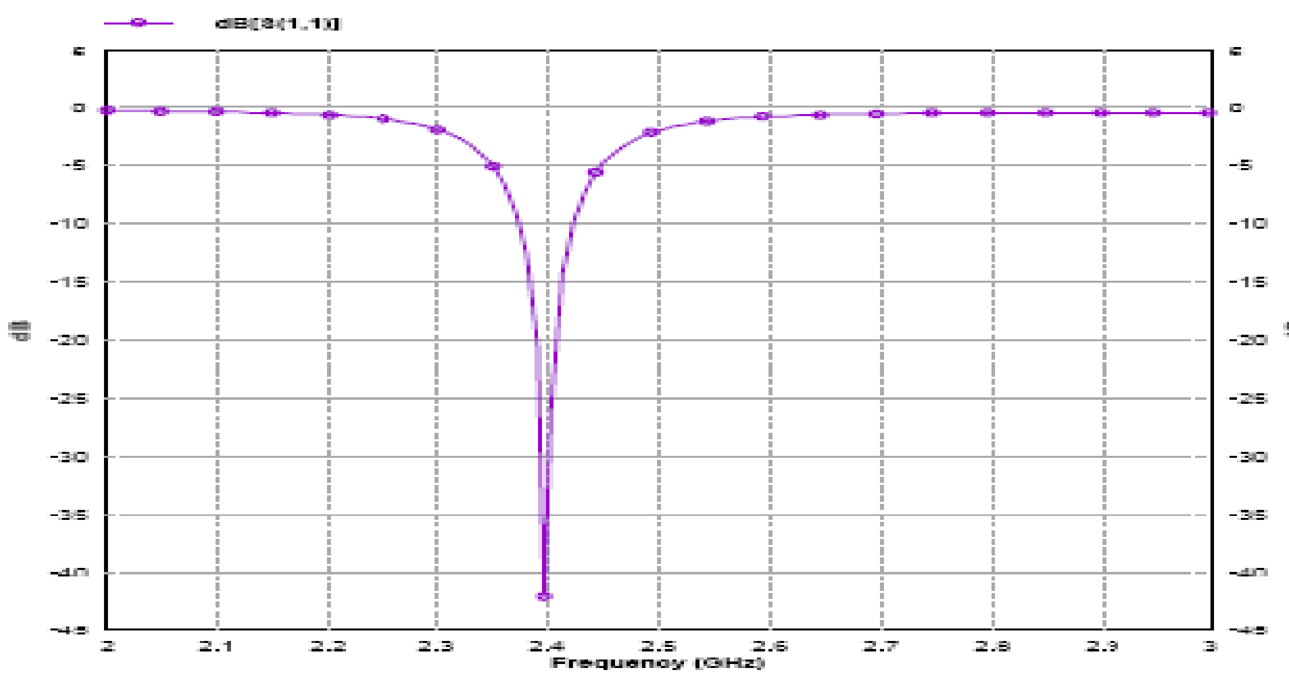


Figure 4.5(e) Return loss is -42.15 (2.4GHz)

4.4.3 Input Impedance :

As has been stated in Chapter 2, we expect pure real impedance at frequencies where the patch resonates, that is, where the patch is designed to radiate. As a result, the input impedance plot in are blow shows the theoretical result, optimization, around the desired radiating frequency, sufficient reactance cancellation can only occur inside a narrow bandwidth. In addition, one needs to match the resonant resistance with the characteristic impedance of the feed line. A small antenna can be tuned to resonate with an appropriate addition of reactance, or it can be made to self-resonate so that the reactance cancellation at resonance happens naturally in the antenna structure. Since adding external reactance for this purpose increases the power loss and it also requires extra space, it is advisable to follow the second alternative

1. **Theoretical result (IE3D):**

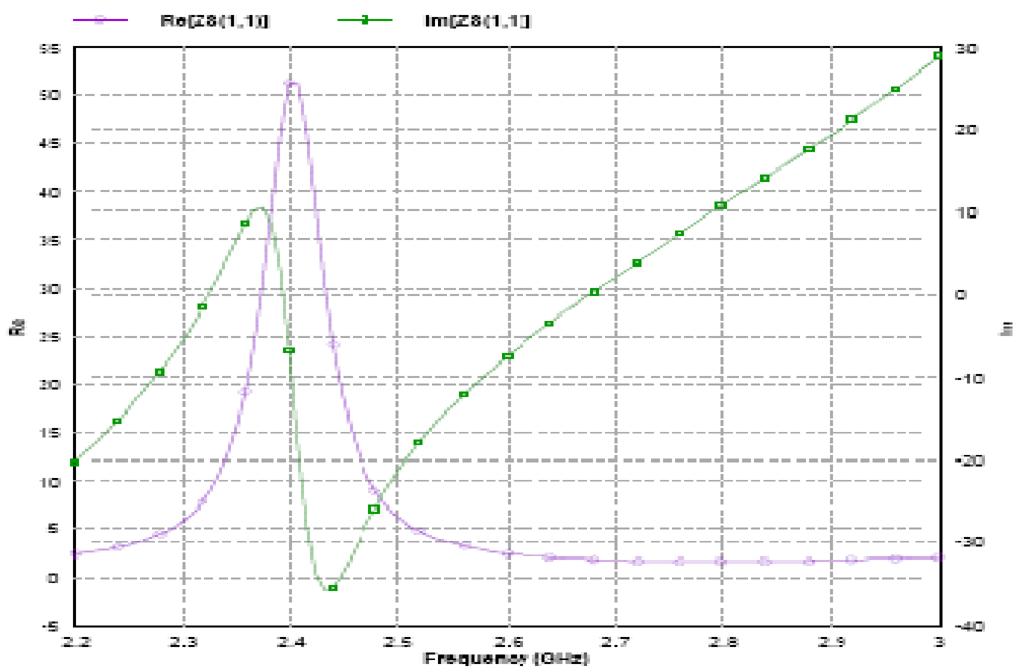


Figure 4.6(a) Input Impedance at 2.392 GHz is 45.99Ω

2. Random Optimization:

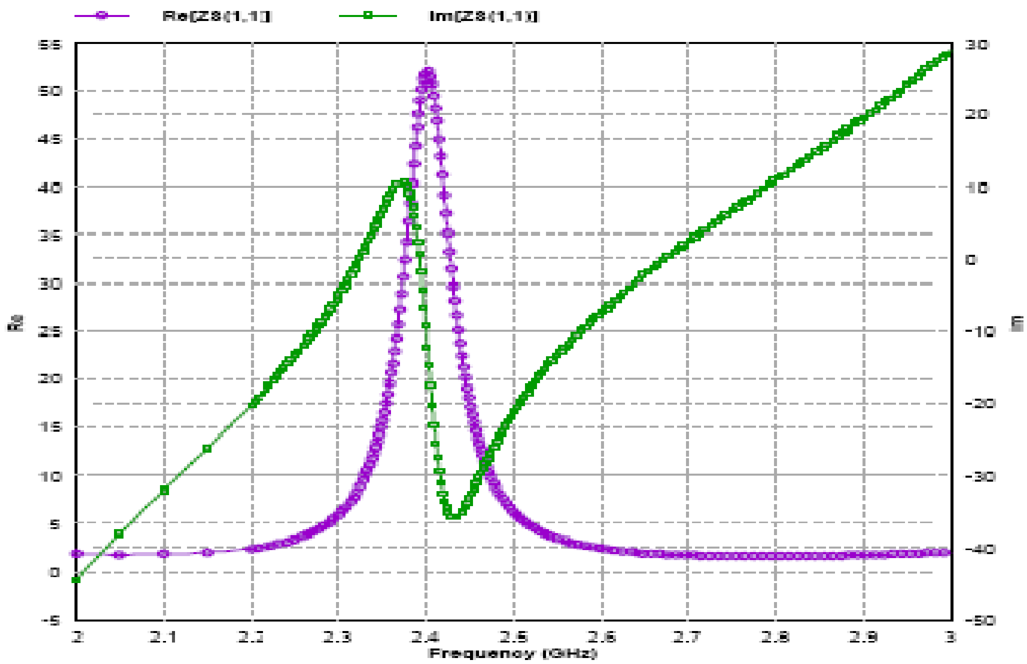


Figure 4.6(a) Input Impedance at 2.3956 GHz is 48.65 Ω

3. Powell Opimization :

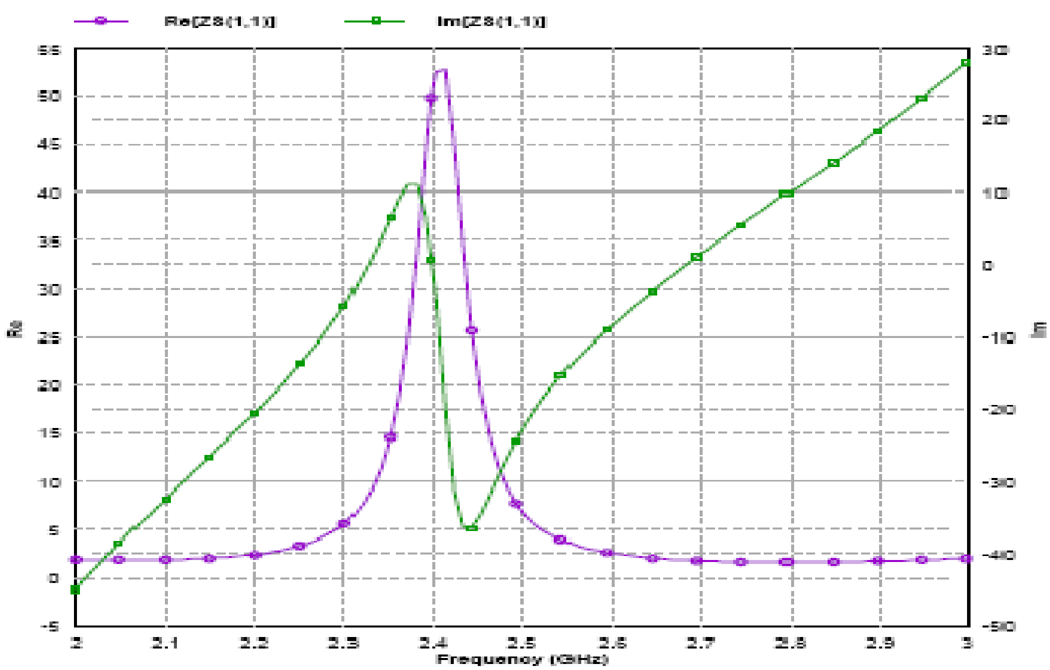


Figure 4.6(a) Input Impedance at 2.4 GHz is 49.78 Ω

4. Genetic Algorithm Optimization:

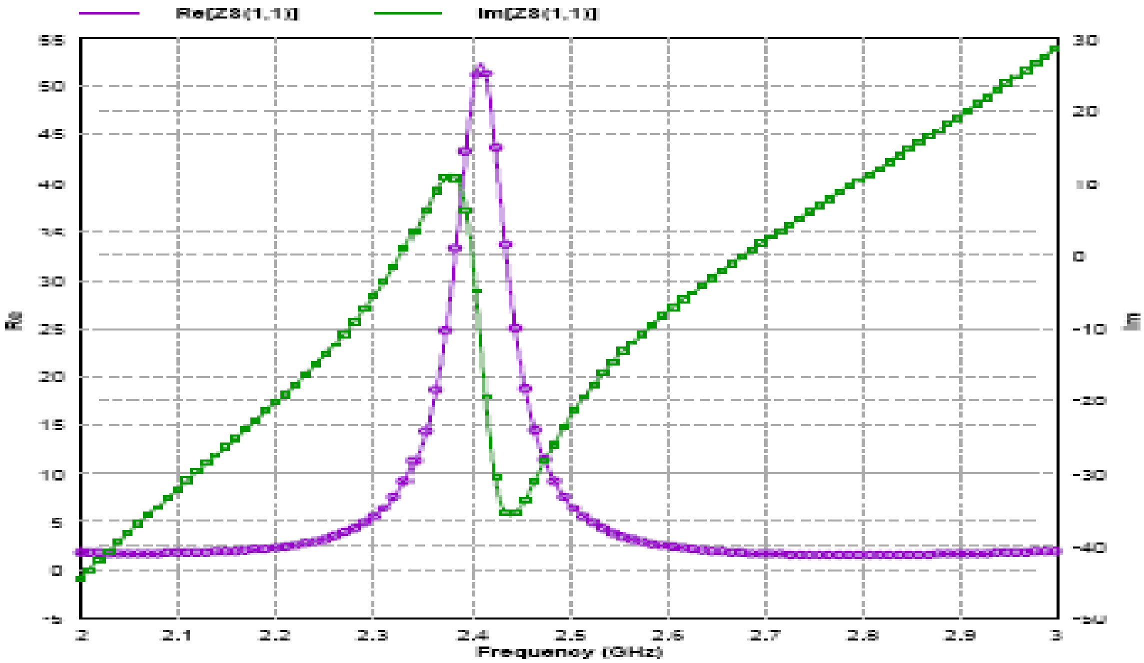


Figure 4.6(a) Input Impedance at 2.4 GHz is 49.70 Ω

5. Adaptive EM Optimizer:

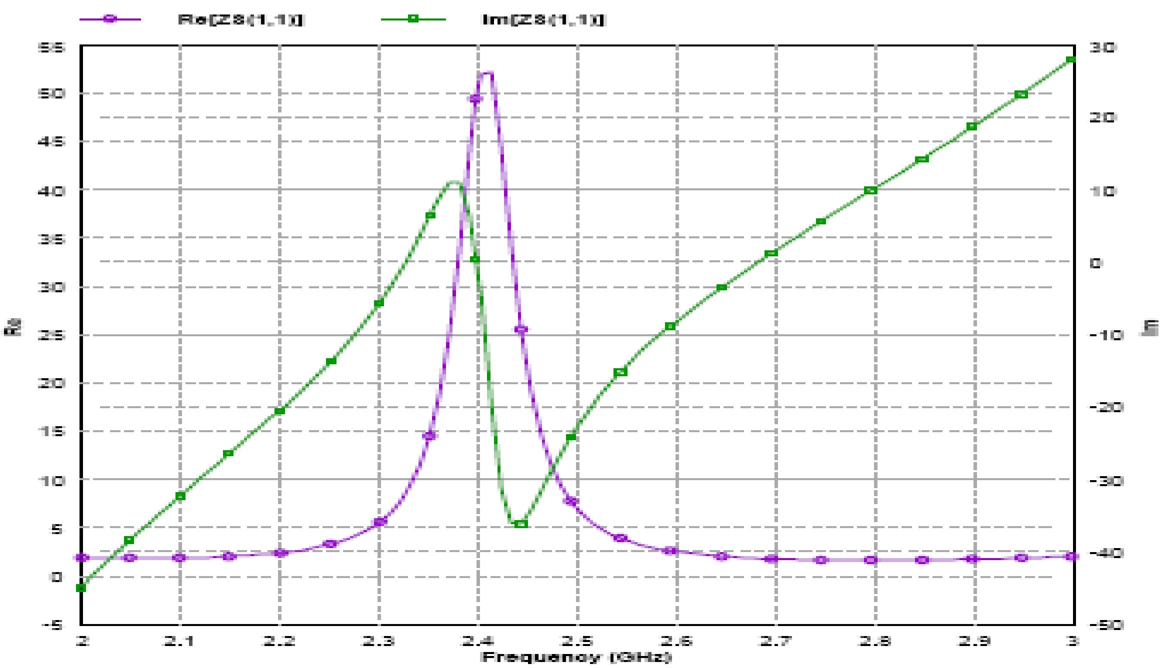


Figure 4.6(a) Input Impedance at 2.4 GHz is 49.43 Ω

4.4.4 Radiation Pattern Plot

A Microstrip patch antenna radiates normal to its patch surface. The elevation pattern for Φ=0 and Φ=90 degrees would be important, below show the 2D radiation pattern of the antenna at the designed frequency for Φ=0 and Φ=90 degrees.

1. **Theoretical result (IE3D):**

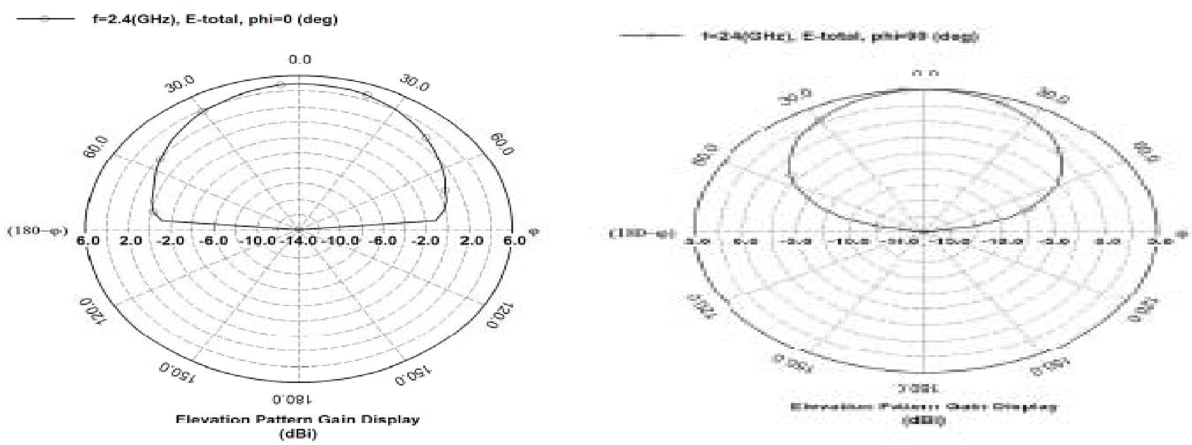


Fig.4.7 (a) Elevation Pattern for Φ=0 and Φ= 90 degrees at f=2.4 GHz

2. **Random Optimization:**

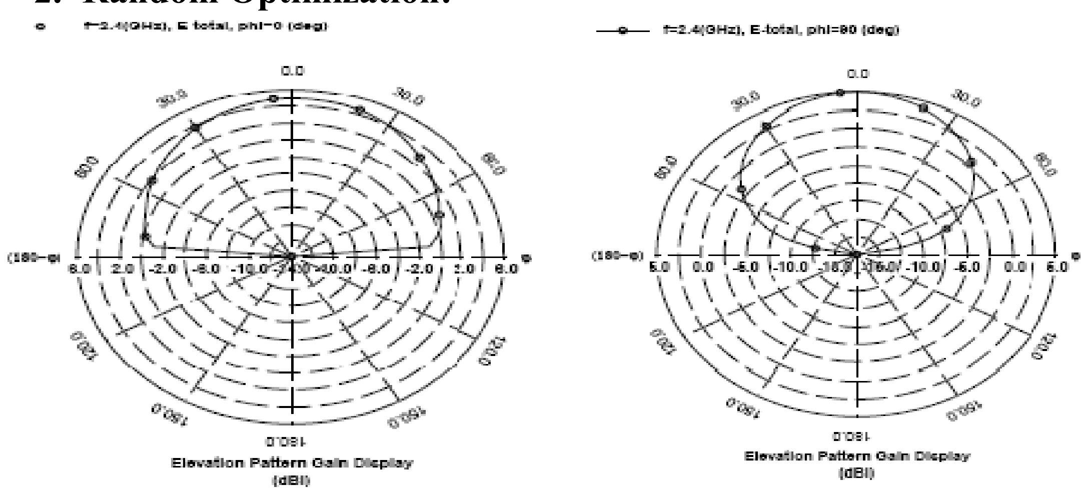


Fig.4.7 (b) Elevation Pattern for Φ=0 and Φ= 90 degrees at f=2.4 GHz

3. Powell Opimization :

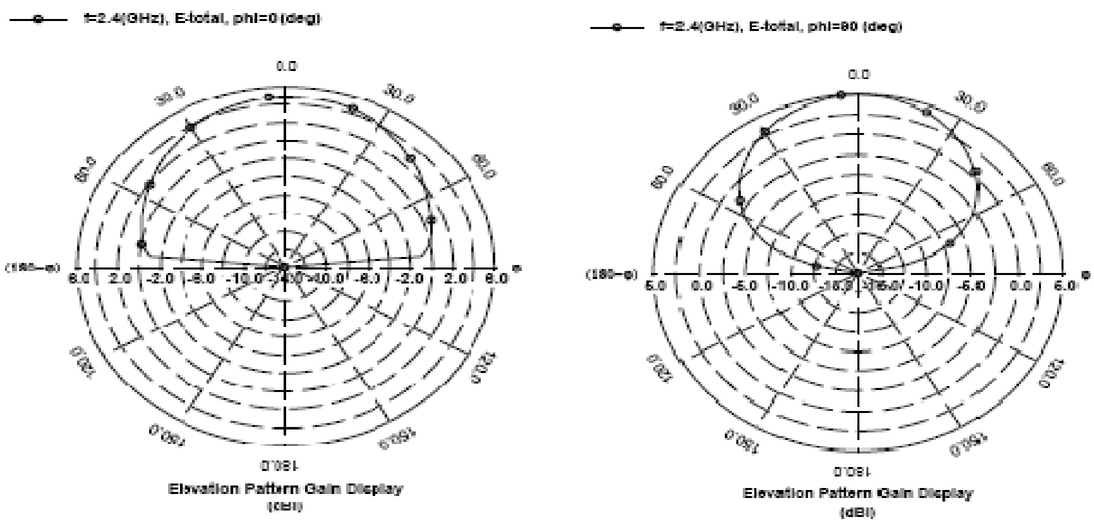


Fig.4.7 (c) Elevation Pattern for Φ=0 and Φ= 90 degrees at f=2.4 GHz

4. Genetic Algorithm Optimization:

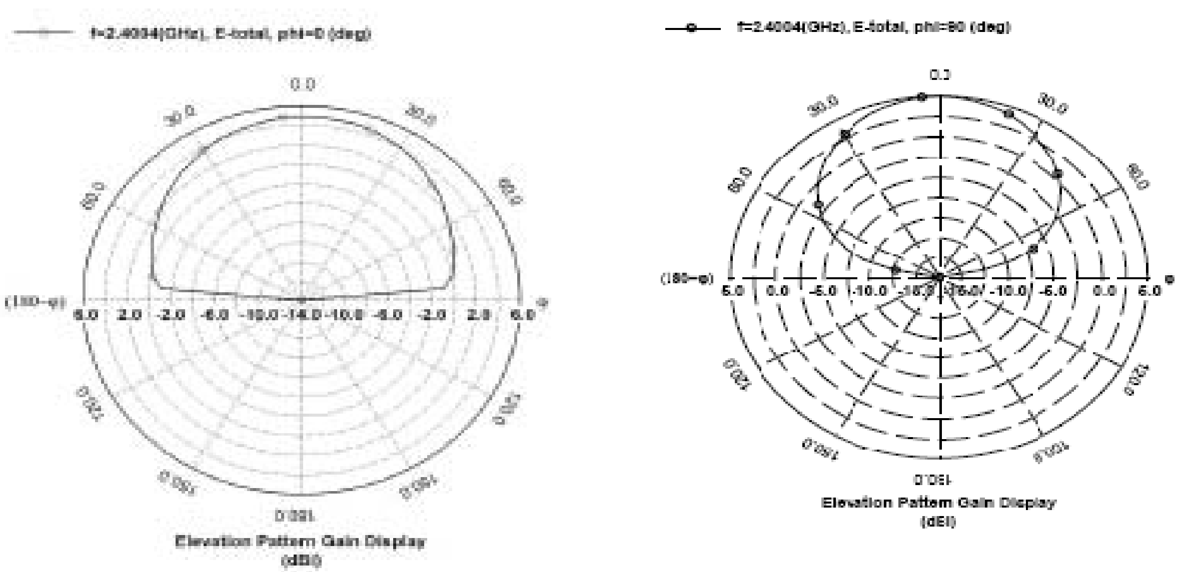


Fig.4.7 (d) Elevation Pattern for Φ=0 and Φ= 90 degrees at f=2.4 GHz

5. Adaptive EM Optimizer:

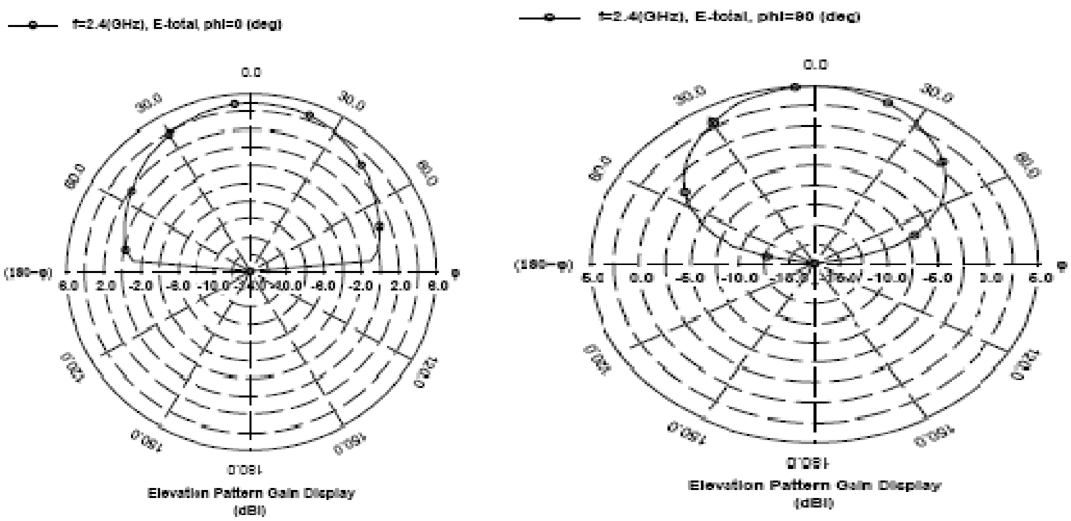


Figure 4.7(e) Elevation Pattern for Φ*=0 and* Φ*= 90 degrees* at f=2.4 GHz

In conclusion, it can be seen from the simulation results that, the antenna performs well at the operating frequency. There is also some deviation from the theoretically expected operating frequency, the main reason for this is the discretization applied during simulation. Also from the radiation pattern seen above, maximum of the energy radiated is away from the user_s head, which guarantees that an acceptable level for the specific absorption rate by the user_s head can be maintained. But as can be seen from the return loss snap taken from the simulation, one can see that the whole of the 2.4 GHz band is not covered by the antenna bandwidth, therefore some work is needed to be done to tackle this.

4.4.5 Gain vs. Frequency Plot

In Microstrip patch antenna the gain is between 5-8 dB. The figure 4.8(a), 4.8(b), 4.8(c), 4.8(d) and 4.8(e) respectively shows the theoretical result, Random Optimization, Powel optimization, Genetic Algorithm Optimization and the Adaptive EM Optimizer at the desired frequency. In frequency 2.4 GHz the gain is maximum when using the Adaptive EM Optimization technique.

1. **Theoretical result (IE3D):**

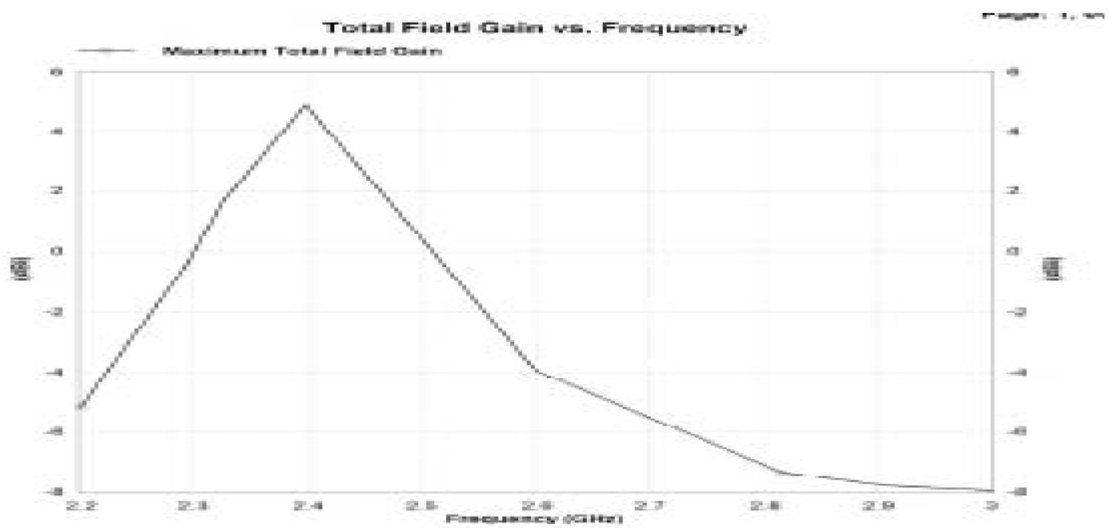


Figure 4.8(a) Gain of the patch is 4.80766 dB at f=2.392 GHz

2. **Random Optimization:**

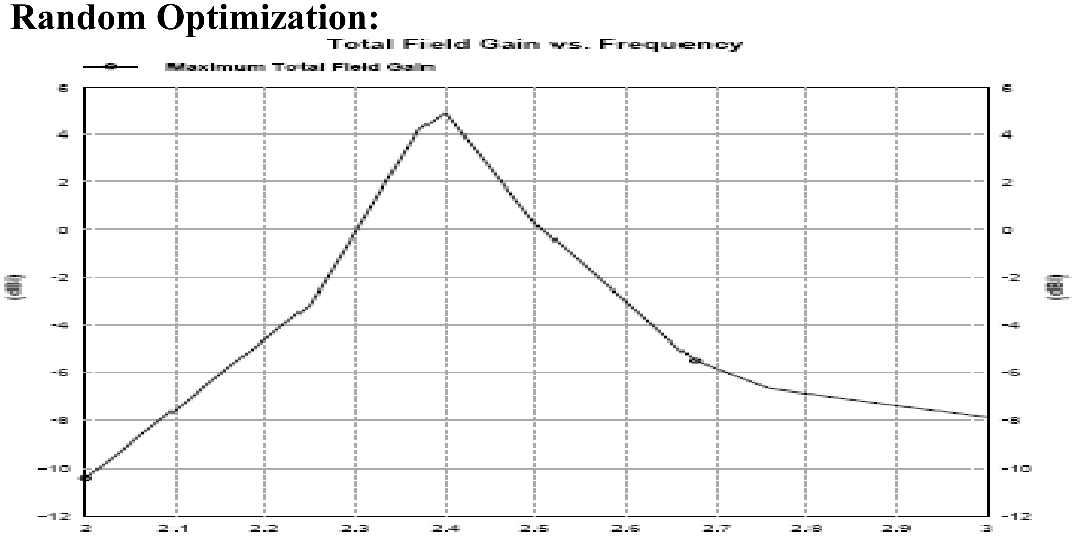


Figure 4.8(a) Gain of the patch is 4.808 dB at f=2.3956 GHz

3. Powell Opimization :

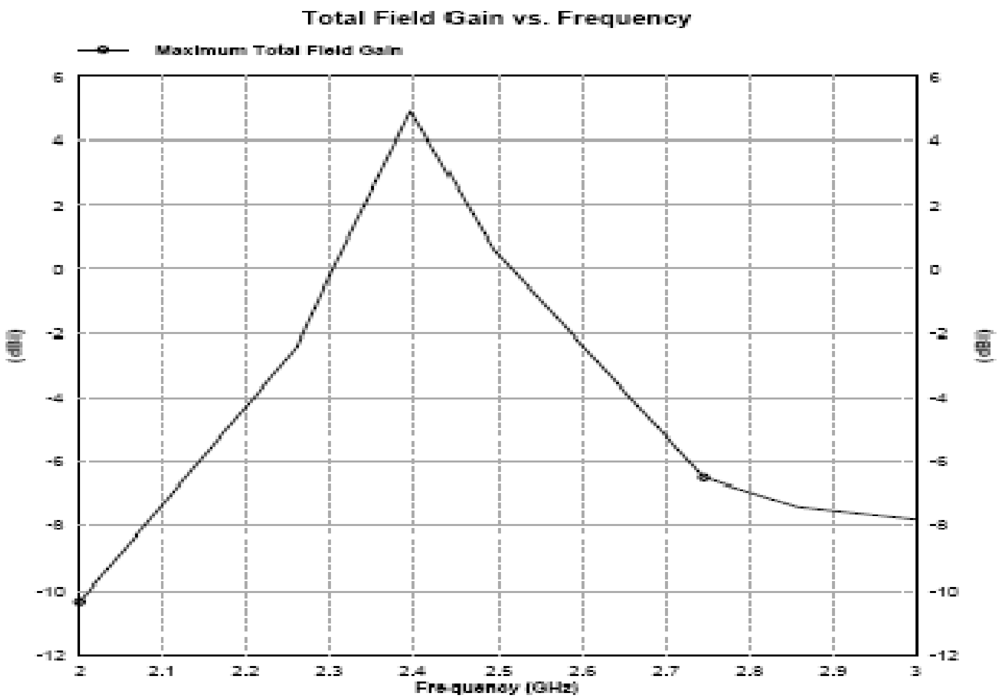


Figure 4.8(a) Gain of the patch is 4.908 dB at f=2.4GHz

4. Genetic Algorithm Optimization:

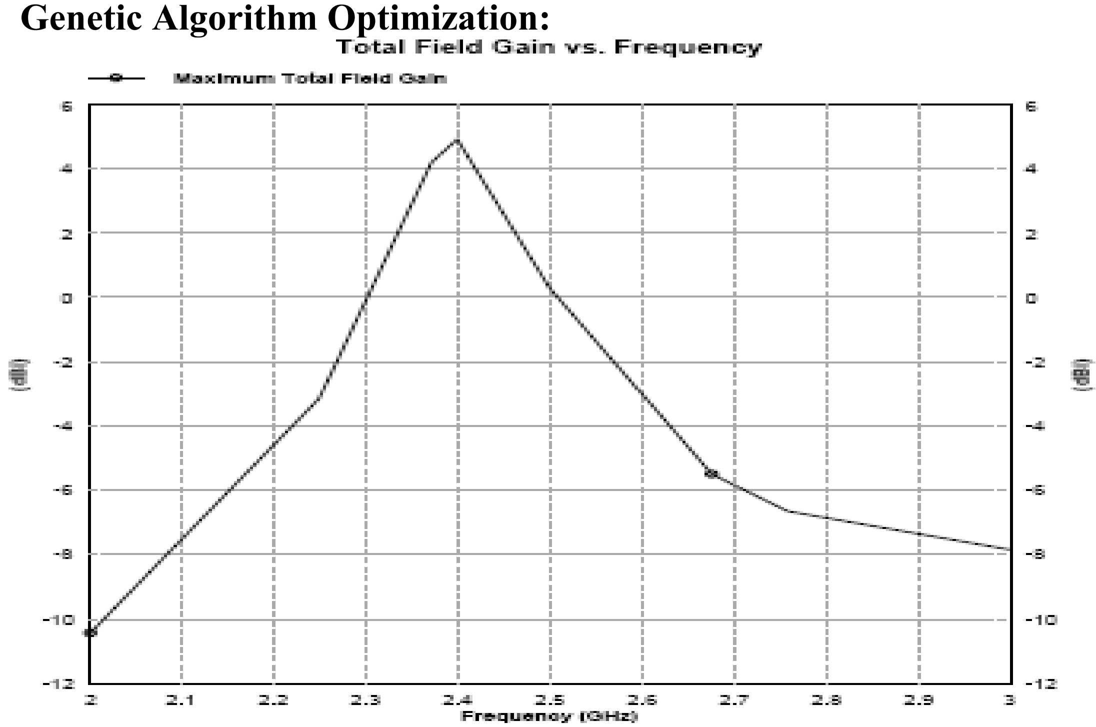


Figure 4.8(a) Gain of the patch is 4.928 dB at f=2.4GHz

5. **Adaptive EM Optimizer:**

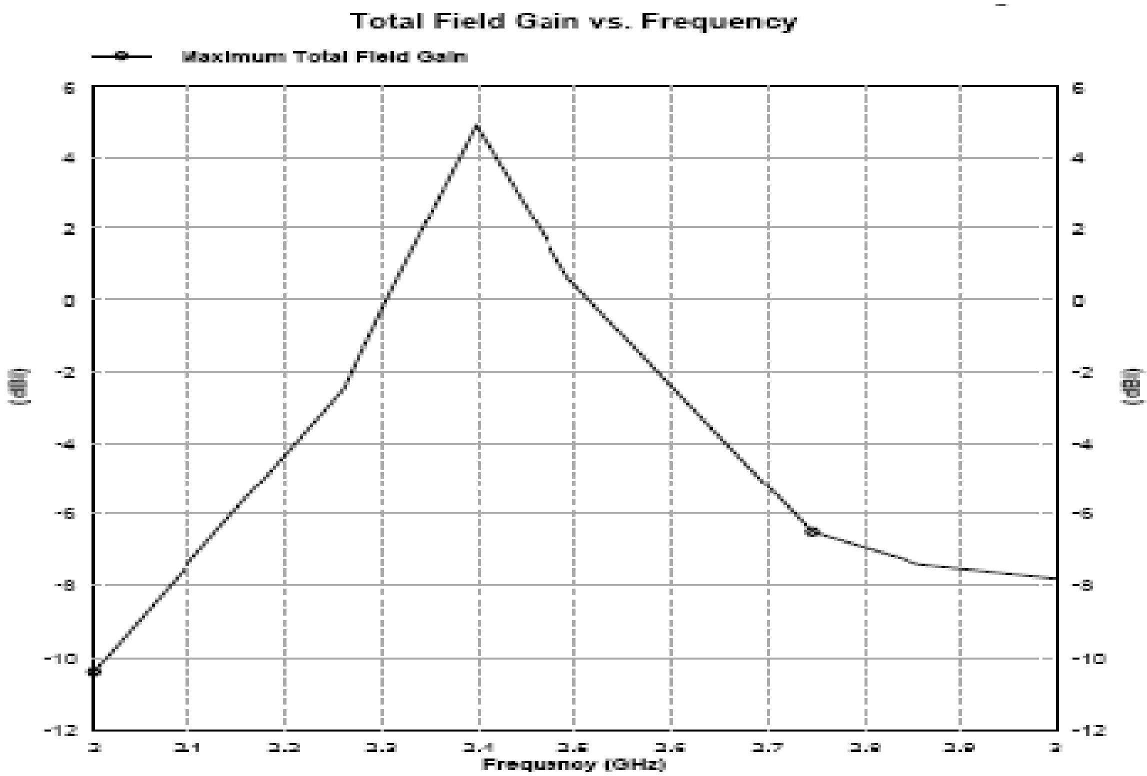


Figure 4.8(a) Gain of the patch is 4.978 dB at f=2.4GHz

4.4.6 VSWR Plot

Voltage standing wave ratio (VSWR) of Microstrip antenna shown in below figure shows the theoretical result and the optimization of the patch. In case of Microstrip patch antenna the value of VSWR is always less than 2. At f= 2.4 GHz the value of VSWR is 1.01 using the Fast EM Optimization.

1. **Theoretical result (IE3D):**

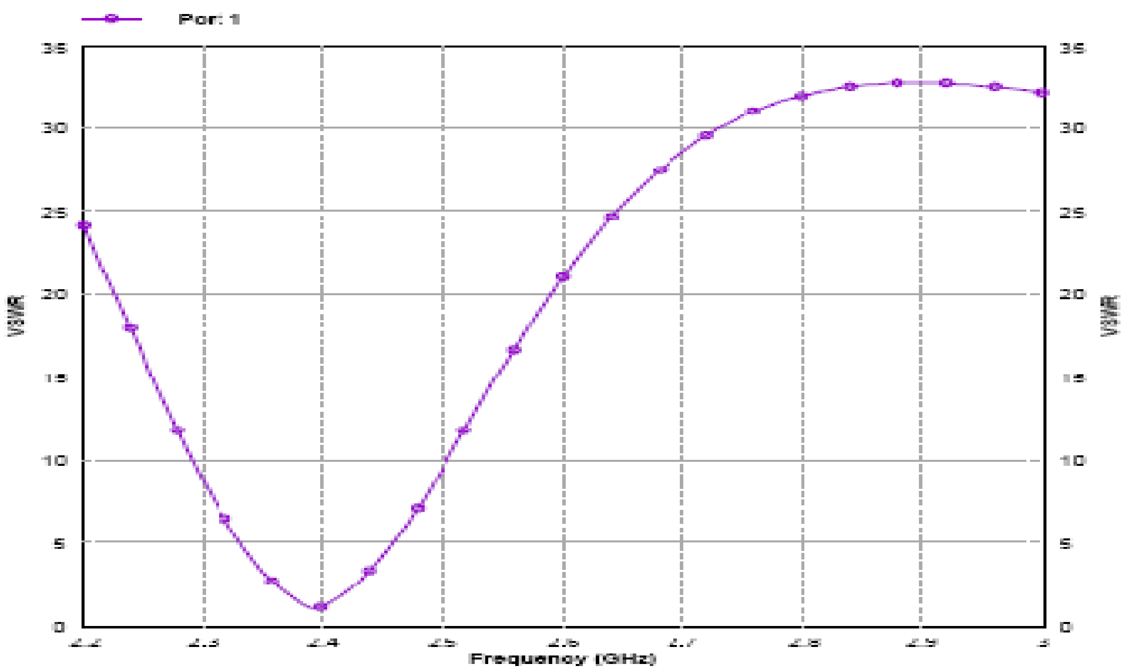


Figure 4.9(a) VSWR of Microstrip patch antenna is 1.112 at f=2.392

2. **Random Optimization:**

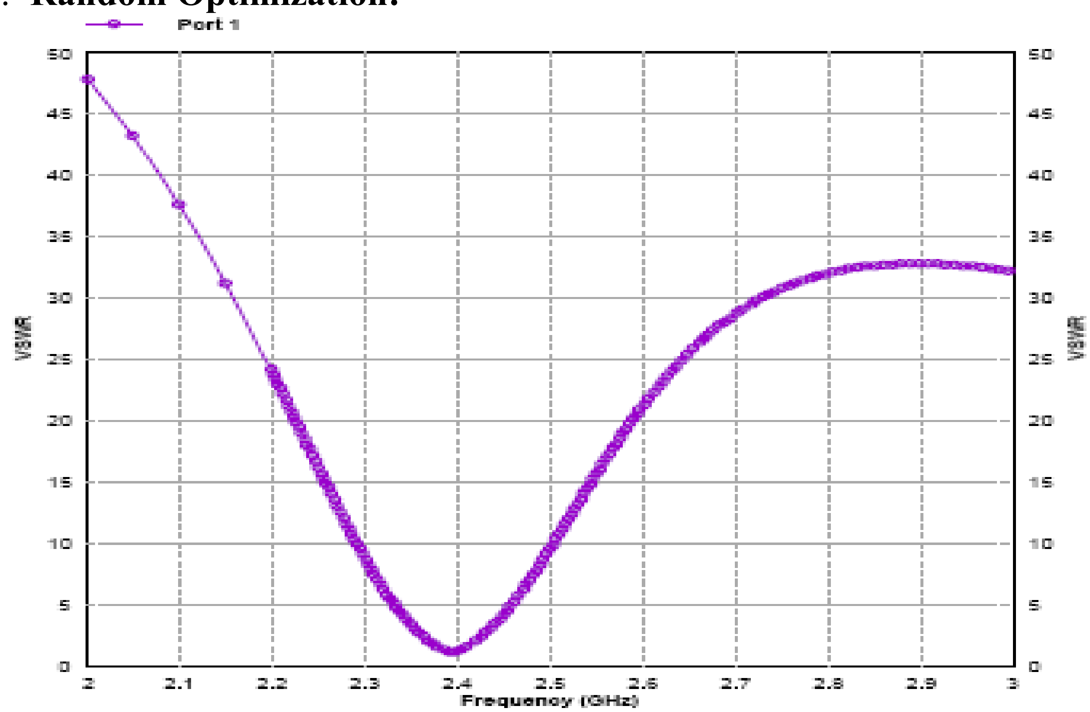


Figure 4.9(a) VSWR of Microstrip patch antenna is 1.1041 at f=2.395

3. **Powell Opimization :**

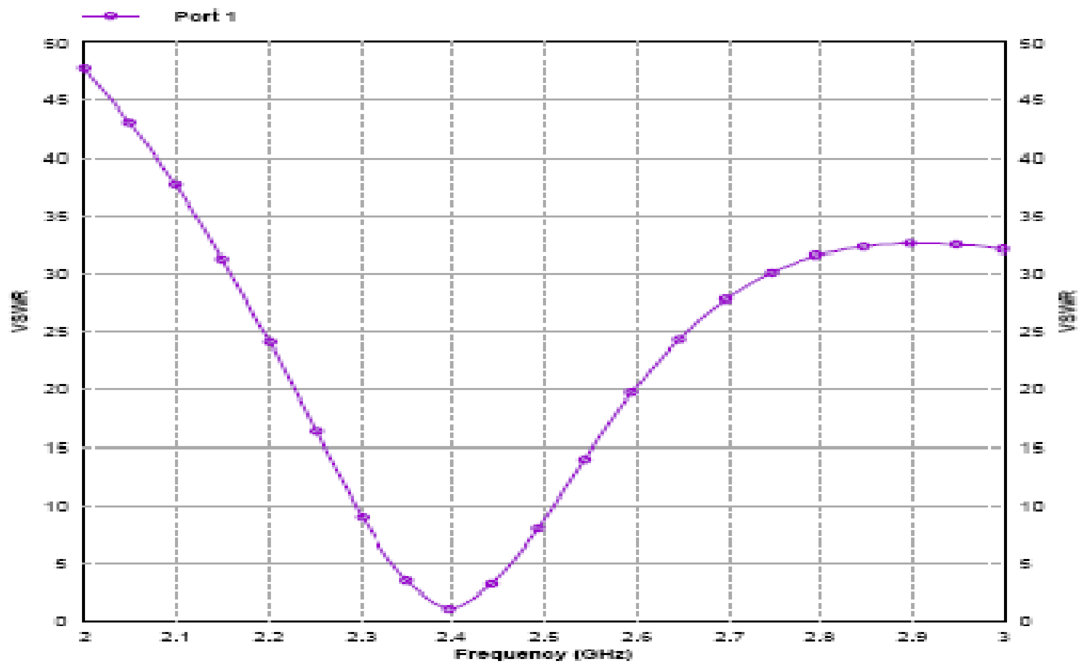


Figure 4.9(a) VSWR of Microstrip patch antenna is 1.0131 at f=2.4

4. **Genetic Algorithm Optimization:**

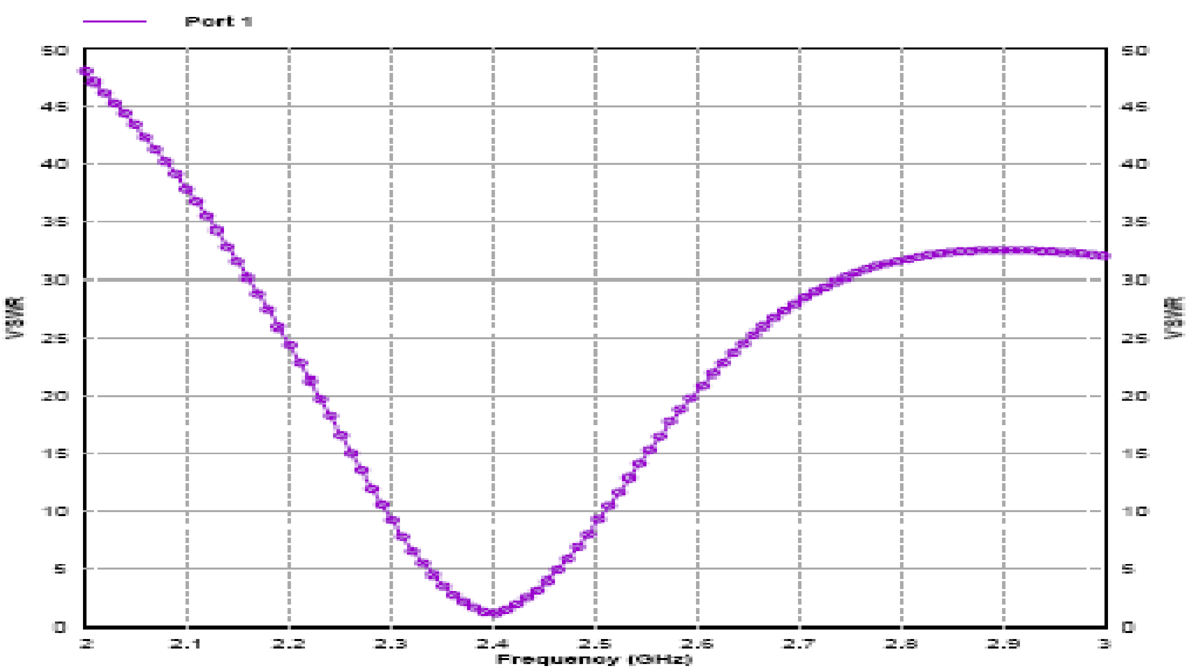


Figure 4.9(d) VSWR of Microstrip patch antenna is 1.021 at f=2.4

5. **Adaptive EM Optimizer:**

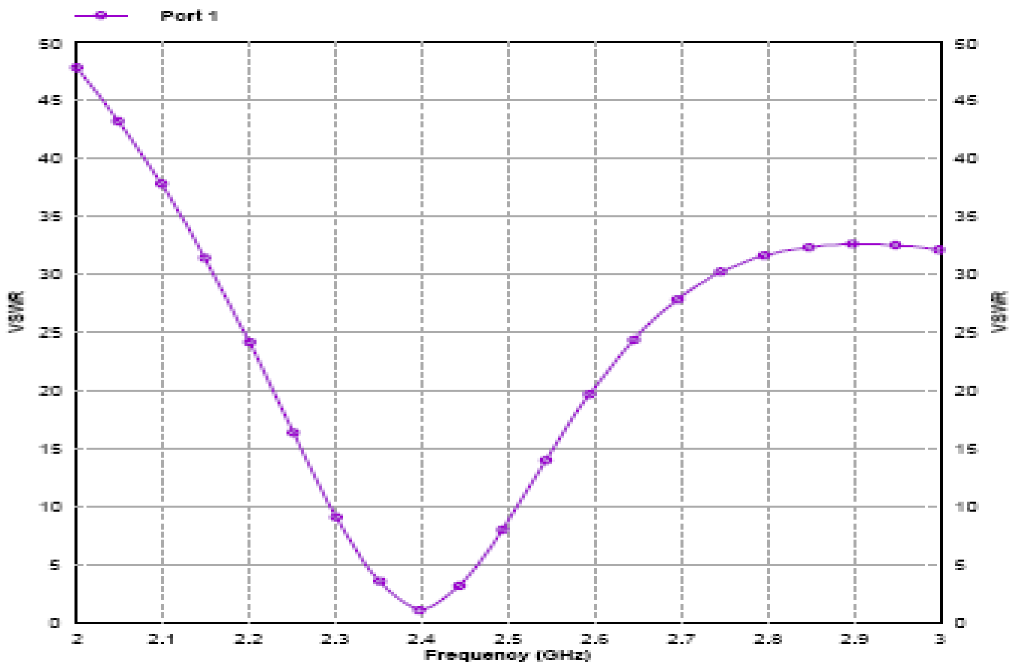


Figure 4.9(e) VSWR of Microstrip patch antenna is 1.016 at f=2.4

4.5 Compression between the Theoretical, Random Optimization, Powel Optimization, Genetic algorithm optimization and Fast EM Optimization results of single band antenna:-

Antenna Parameter	**Theoretical result (IE3D**	**Random Optimization:**	**Powell Opimization**	**Genetic Algorithm Optimization**	**Adaptive EM Optimizer:**
Frequency (f_1) [GHz] And Return loss(dB)	2.392GHz (-25.54 dB)	2.395GHz (-36.1dB)	2.4GHz (-44.1dB)	2.4GHz (-39.76dB)	2.4GHz (-42.15dB)
VSWR for f_1	1.112	1.104	1.013	1.021	1.016
Impedance for f_1(Ω)	45.99	48.65	49.78	49.70	49.85
Gain (dB)	4.807	4.808	4.908	4.928	4.978

CHAPTER 5 DUAL BAND MICROSTRIP ANTENNA

5.1 Dual-Band Antenna Concept

In principle, multi-band planar antennas should operate with similar features, both in terms of radiation and impedance matching, at two or more separate frequencies. It is known, a simple rectangular Microstrip patch can be regarded as a cavity with magnetic walls on the radiating edges. The first three modes with the same polarization can be indicated by TM_{10} , TM_{20} and TM_{30} . TM_{10} is the mode typically used in practical applications; TM_{20} and TM_{30} and are associated with a frequency approximately twice and triple of that of the mode. This provides the possibility to operate at multiple frequencies. In practice, the TM_{20} and the TM_{30} modes cannot be used owing to the facts that the TM_{20} pattern has a broadside null and the pattern has grating lobes.

The simplest way to operate at dual frequencies is to use the first resonance of the two orthogonal dimensions of the rectangular patch, i.e., the $TM_{10}$and the TM_{01} modes. In this case, the frequency ratio is approximately equal to the ratio between the two orthogonal sides of the patch. The obvious limitation of this approach is that the two different frequencies excite two orthogonal polarizations. Anyway, this simple method is very useful in low-cost short-range applications, where polarization requirements are not pressing.

The most popular technique for obtaining a dual-frequency behavior is to introduce a reactive loading to a single patch, including stubs, notches, pins and, capacitors, and slots . By these reactive-loading approaches, one can modify the resonant mode of the patch, so that the radiation pattern of the higher order mode could be similar to that of the fundamental mode. This indicates that the use of a single feed for both frequencies on a single radiating element can be realized. In 1995, a rectangular patch with two narrow slots etched close to and parallel to the radiating edge was used to obtain the dual-frequency operation proposed by S. Maci [7]. In this dual-frequency design, the two operating frequencies are associated with the and modes of the unslotted rectangular patch. In addition, this two operating frequencies have the same polarization planes and broadside radiation patterns, with a frequency ratio within the range of 1.6-2.0 for the inset feed case The above approach characterizes a first category of dual-frequency patch antennas, which will be identified as 1) orthogonal mode dual-frequency patch antenna [9] . This category can be extended to any kind of patch shape that offers two cross-polarized resonant modes. Most of the other dual-frequency patch antennas found in the literature can be subdivided into 2) multi-patch dual frequency antennas [9], and 3) reactively-loaded dual-frequency patch antennas

5.2 Geometry of Proposed Dual Band Antenna:

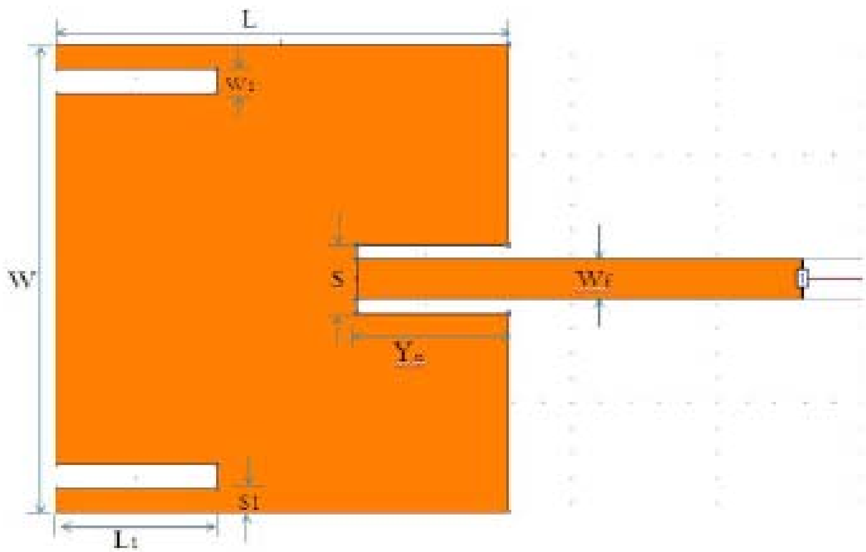


Figure 5.1 Geometry of dual band antenna

Calculation of length (L) and width (W) of Microstrip patch antenna is discussed in chapter 4 when we creating a single band Microstrip antenna. In Table 5.1 shows the parameter of Dual-Band Rectangular Microstrip antenna.

Design of Dual Band Microstrip Patch Antenna	
Width of the Patch(W)	46.9 mm
Effective dielectric constant of the Patch(ϵ_{reff})	2.2922
Length of the Patch(L)	39.6 mm
Input Resistance of the Patch (R_{in})	50 Ω
Inset Depth of the Patch (y_o)	13 mm
Width of Microstrip line (w_f)	4.2 mm
Width of slots(w_1)	1.4 mm
Length of slots(L_1)	14.2 mm
Width of non-radiating edge(S_1)	1.4 mm

Table 5.1 Calculated result of Dual Band rectangular patch antenna

.5.3 Dual Band Antenna Design Method

The antenna structure (Fig. 5.1) consists of a rectangular patch with two slots into one of the radiating edges, and is excited using an inset planar feed. The patch design consists of two stages. The first stage involves the creation of an additional $TM_{0\delta}$ Resonant mode at a with a resonant frequency above that of the fundamental TM_{01} mode, with the same polarization sense. The second stage is to simultaneously reduce the input impedance of both modes to 50Ω at resonance through the use of an inset feed.

Stage 1: Creation of Two Resonant Modes

The first point to note in the design process is the effect of slot separation on the patch design. With reference to the value of slot separation, experimental results have shown that placing the slots close to the non radiating edges of the patch increases the effect of slot length on resonant frequency. This gives greater freedom to tune the resonant frequency of the $TM_{0\delta}$ mode. In view of this design, **s1** has been fixed at 1.4 mm. considering the value of slot width **w1**, the

requirement to achieve impedance matching of both TM_{01} and $TM_{0\delta}$ modes effectively place a constraint on this value. Increasing the slot width produces an increase in input impedance of the TM_{01} mode. As the slot width increases further, a stage is reached where the input impedance is too high for traditional impedance matching. A further reason for placing a limit on the value of slot width is the fact that the resonant frequency of the TM_{01} mode remains largely unaffected. For this design, experimental results indicate that the slot-width value should not exceed 3 mm. Placing this constraint on the slot-width value is beneficial from a designers point of view, as only the effect of slots on the additional mode need be considered. This reduces the complexity of the design process. Regarding the effect of slot length L_1 on creating an additional $TM_{0\delta}$ mode, experimental results indicate that the slot length *l*1 must take on a value of between 40% *L* and 56% *L*. Increasing
L_1 within these constraints can produce a frequency ratio of between 1.03 and 1.29.

Stage 2: Achieving Impedance Matching at Both Frequencies

The first part of the impedance-matching procedure is to produce an equal value of input impedance at both resonant frequencies. This has been achieved by varying the slot width w1.when we increase **w1** the value of input impedance changes. The final stage in the design process involves the use of an inset feed. It is found that increasing the inset feed length y_o can simultaneously reduce the input impedance at both frequencies to **50Ω**. The inset feed has a slight effect on both resonant frequencies and thus slight tuning is required.

5.4 Result and Discussion

5.4.1 Return loss and Antenna Bandwidth

The Inset feed and the two slots used to design the dual band rectangular Microstrip patch antenna. The center frequency is selected as the one at which the return loss is minimum. As described in chapter 2, the bandwidth can be calculated from the return loss (RL) plot. The bandwidth of the antenna for this dual frequency point location using IE3D at Adaptive EM Optimizer is seen to be and due to slots the second frequency is f_2 =3.08 GHz of the antenna for this dual frequency point location using IE3D at Adaptive EM Optimizer is seen to be and due to slots the second frequency is .The frequency ratio is 1.29 for using these dual slots. Below

Figure show the theoretical results and optimized result. The return loss (in dB) is plotted as a function frequency.

1. Theoretical result (IE3D):

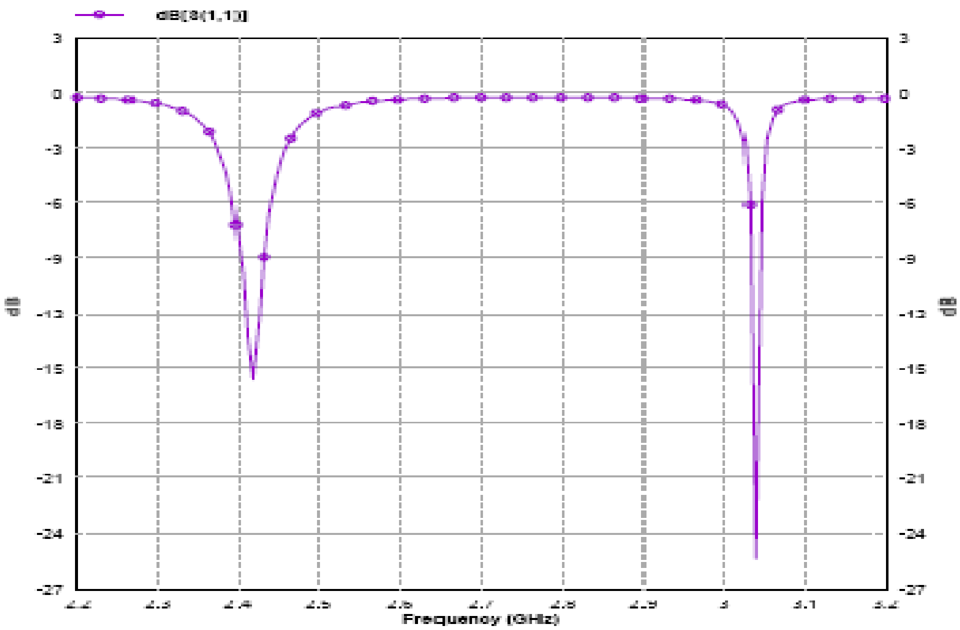


Figure 5.2(a) Return loss is -15.63dB (2.419 GHz) and Return loss is -25.33dB (3.04 GHz)

2. Random Optimization:

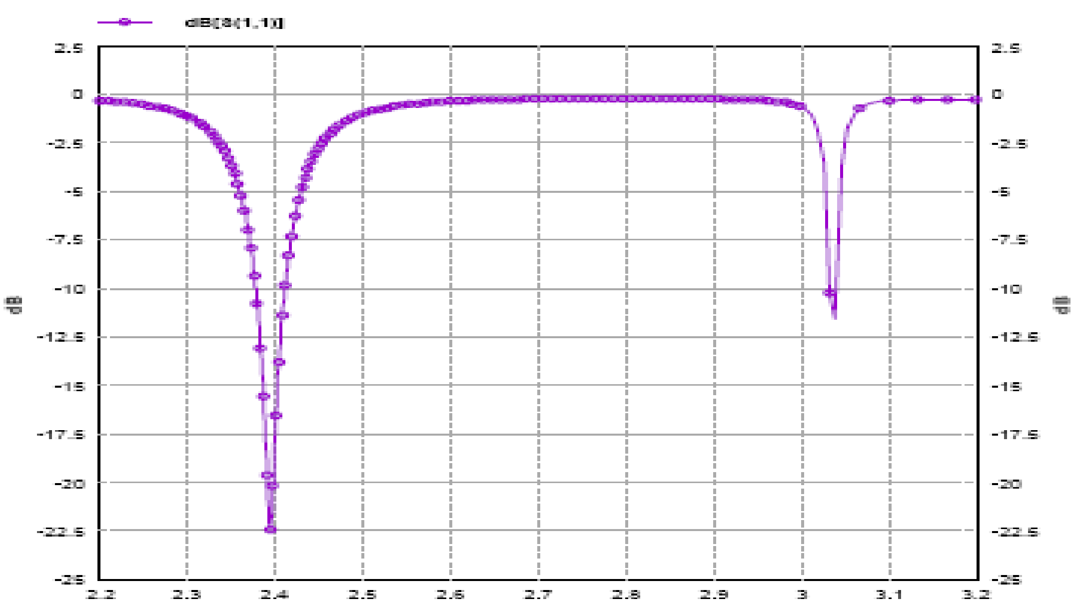


Figure 5.2(b) Return loss is -22.45dB (2.396 GHz) and Return loss is -11.54 (3.04 GHz)

3. Powell Opimization :

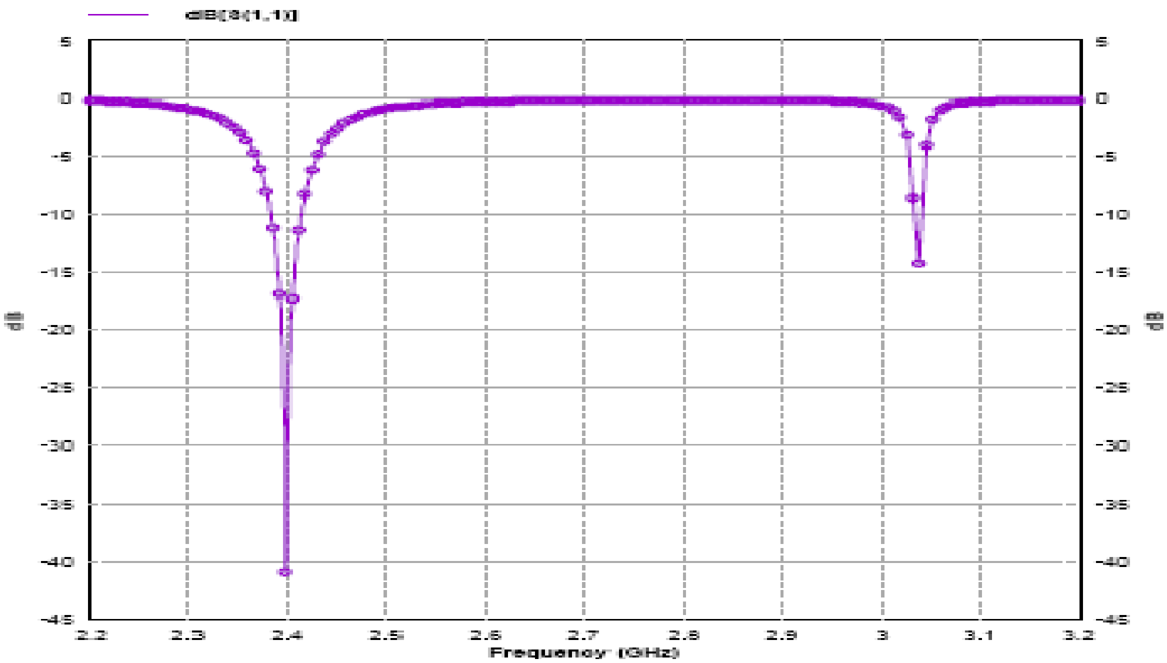


Figure 5.2(c) Return loss is -40.91dB (2.4 GHz) and Return loss is -14.54 (3.04 GHz)

4. Genetic Algorithm Optimization:

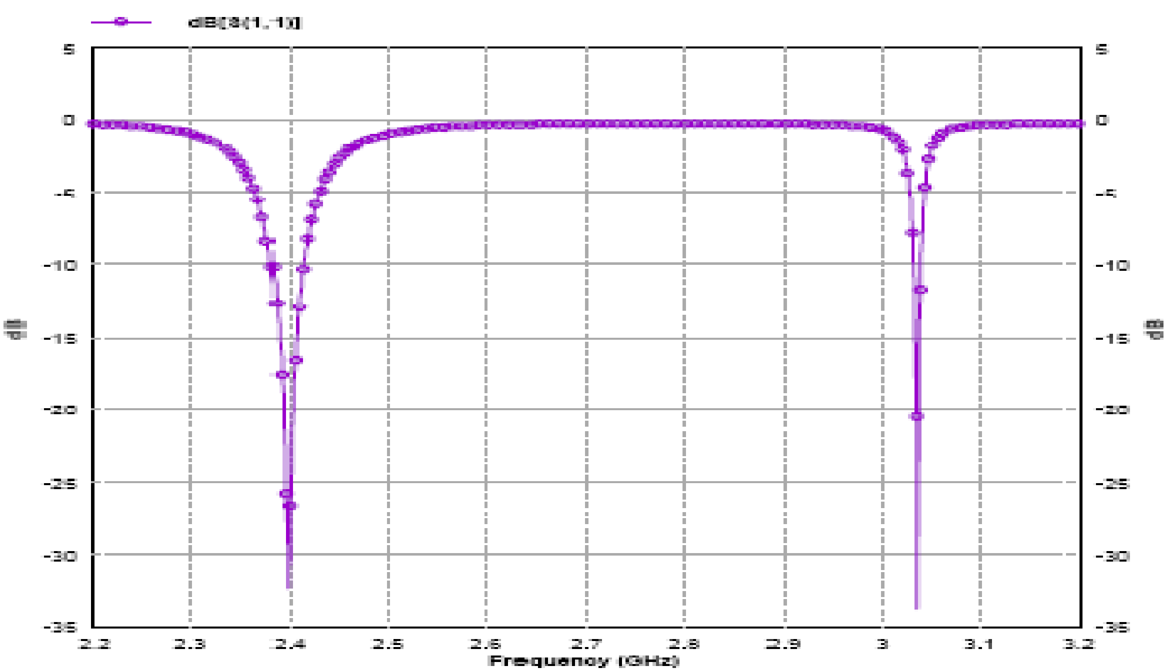


Figure 5.2(d) Return loss is -40.91dB (2.4 GHz) and Return loss is -14.54 (3.04 GHz)

5. Adaptive EM Optimizer:

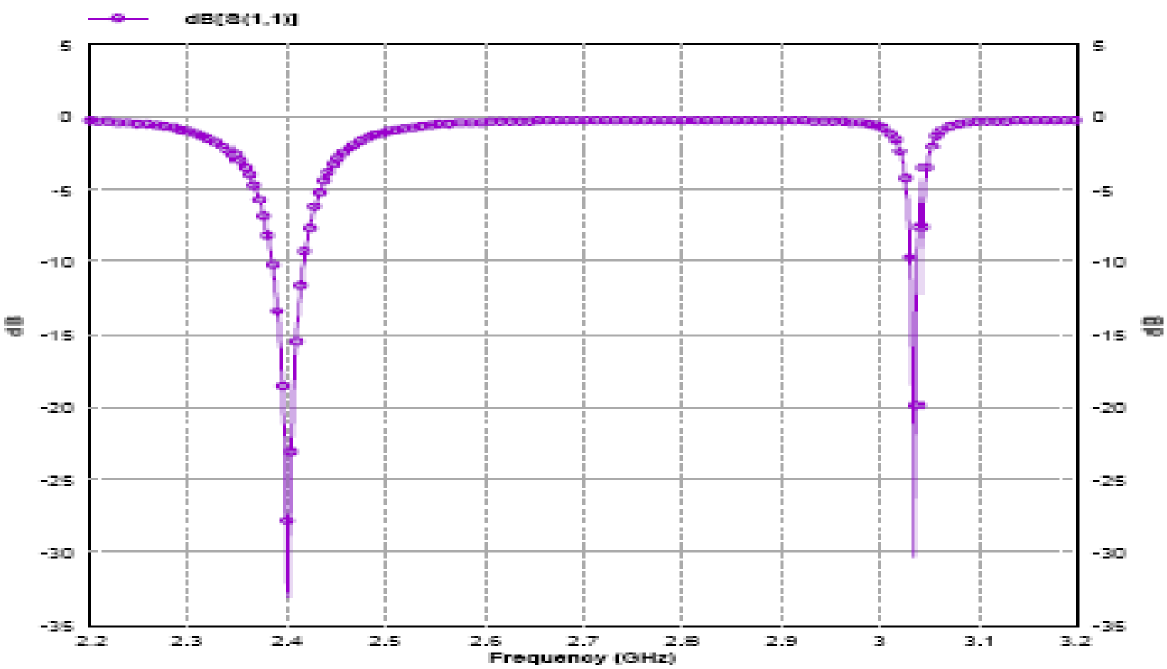


Figure 5.2(a) Return loss is -33.09 dB (2.402 GHz) and Return loss is -30.35 (3.038 GHz)

5.4.2 Radiation pattern plot

A Microstrip patch antenna radiates normal to its patch surface. The elevation pattern for Φ=0 and Φ=90 degrees would be important. Below Figure show the 2D radiation pattern of the antenna at the designed frequency for Φ=0 and Φ=90 degrees.

1. Theoretical result (IE3D):

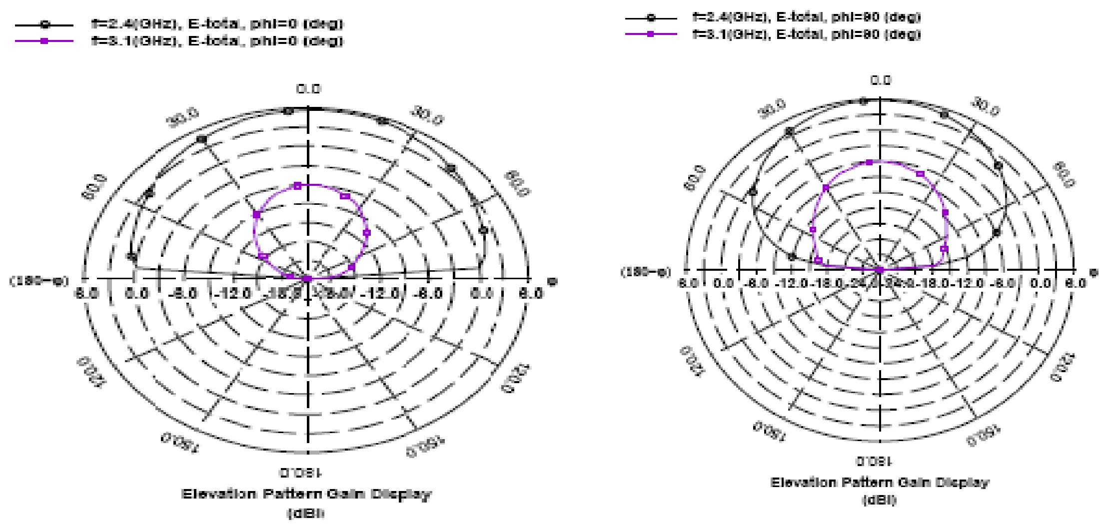


Fig. 5.3(a) (i) Elevation Pattern for Φ=0 and Φ= 90 degrees at f=2.4 GHz

(ii) Elevation Pattern for Φ=0 and Φ= 90 degrees at f=3.1 GHz

2. Random Optimization:

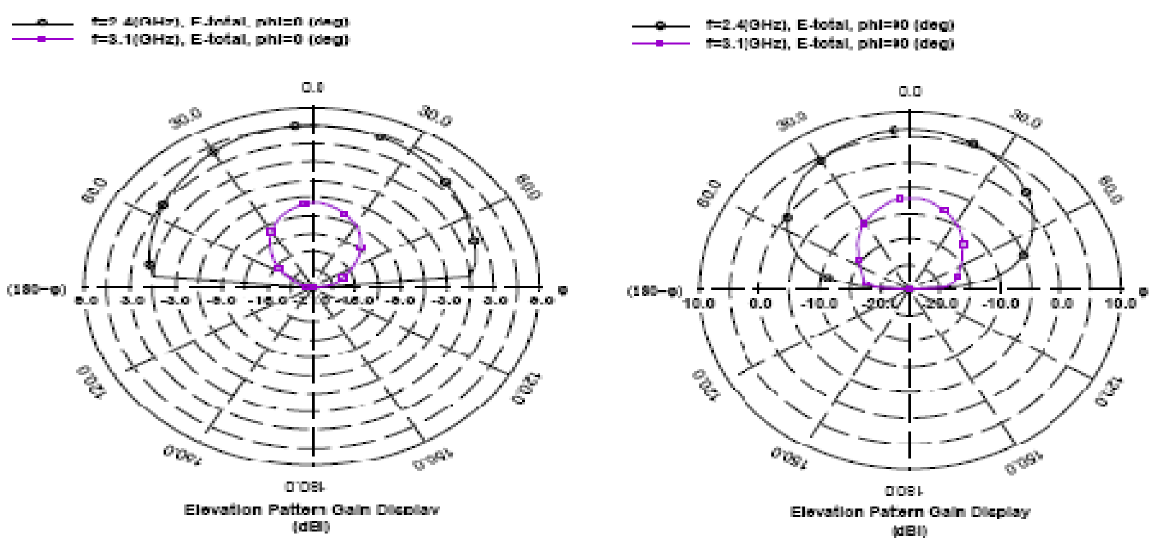


Fig. 5.3(b) (i) Elevation Pattern for Φ=0 and Φ= 90 degrees at f=2.4 GHz

(ii) Elevation Pattern for Φ=0 and Φ= 90 degrees at f=3.1 GHz

3. Powell Opimization :

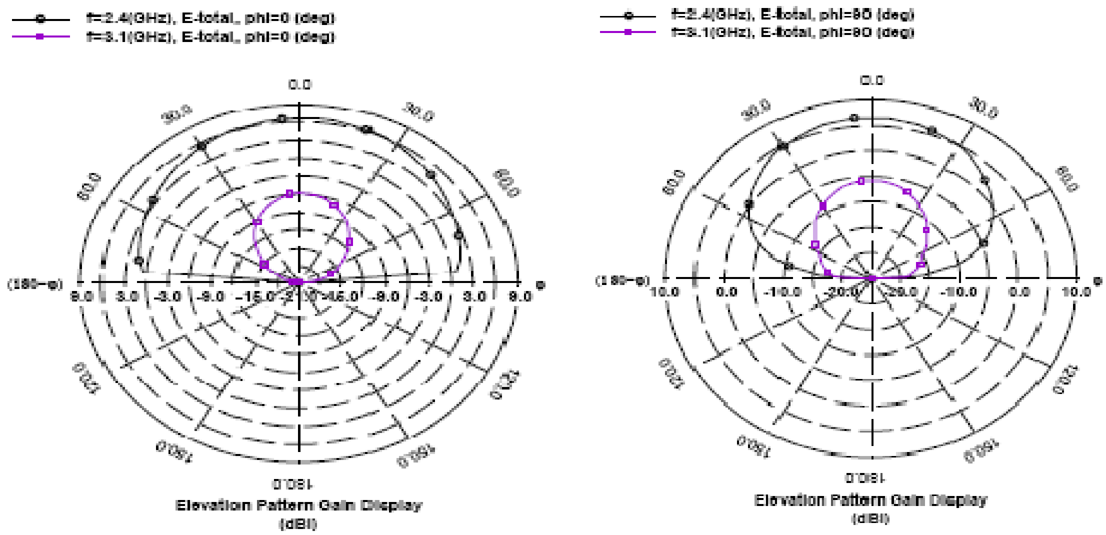


Fig. 5.3(c) (i) Elevation Pattern for Φ=0 and Φ= 90 degrees at f=2.4 GHz

(ii) Elevation Pattern for Φ=0 and Φ= 90 degrees at f=3.1 GHz

4. Genetic Algorithm Optimization:

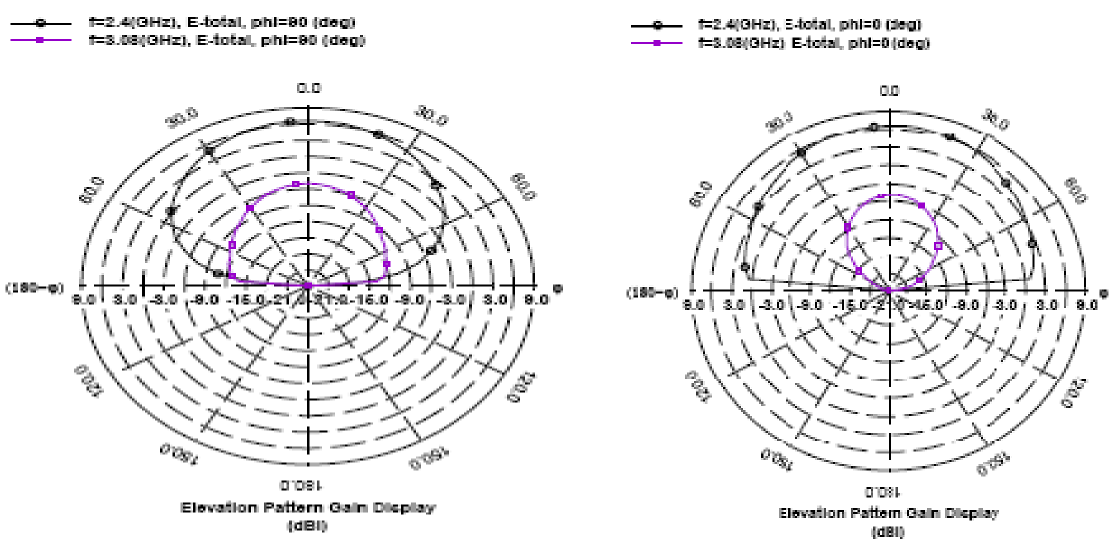


Fig. 5.3(d) (i) Elevation Pattern for Φ=0 and Φ= 90 degrees at f=2.4 GHz (ii) Elevation Pattern for Φ=0 and Φ= 90 degrees at f=3.08 GHz

5. Adaptive EM Optimizer:

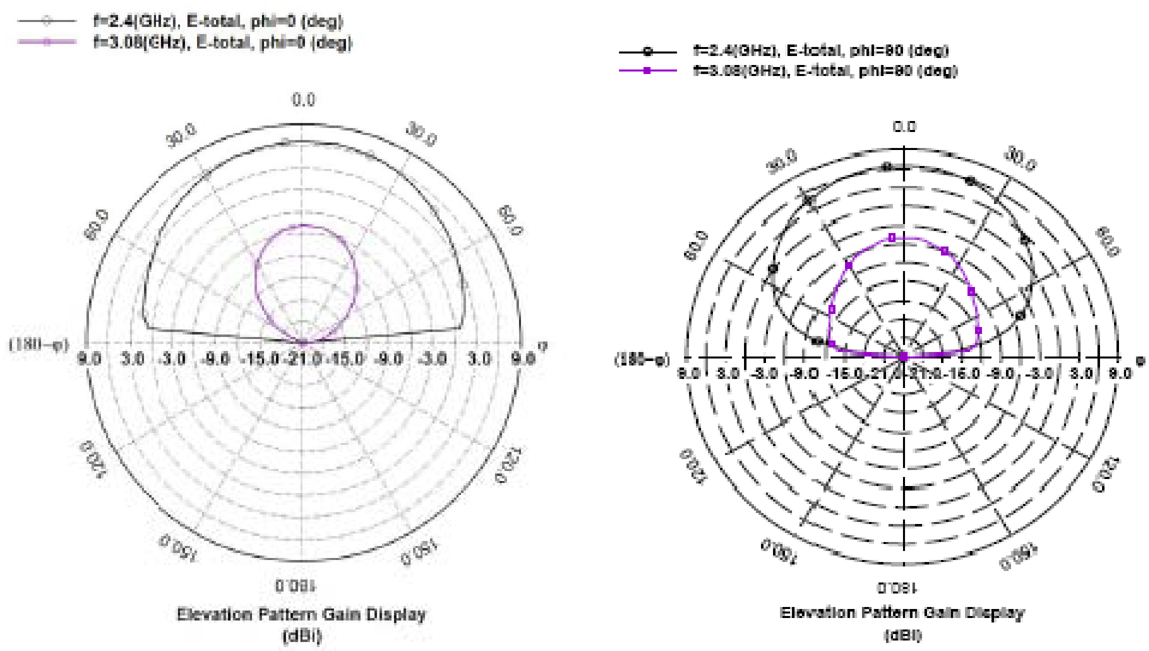


Fig. 5.3(e) (i) Elevation Pattern for Φ=0 and Φ= 90 degrees at f=2.4 GHz

(ii) Elevation Pattern for Φ=0 and Φ= 90 degrees at f=3.08 GHz

5.4.3 VSWR Plot

Voltage standing wave ratio (VSWR) of Microstrip antenna shown in below figure respectively shows the theoretical result and optimization of the patch. In the case of Microstrip patch antenna the value of VSWR is always less than 2 . At f_1 = 2.4 GHz the value of VSWR is 1.08 and at f_2 =3.08 GHz the value of VSWR is 1.3 using the Adaptive EM Optimizer .

1. **Theoretical result (IE3D):**

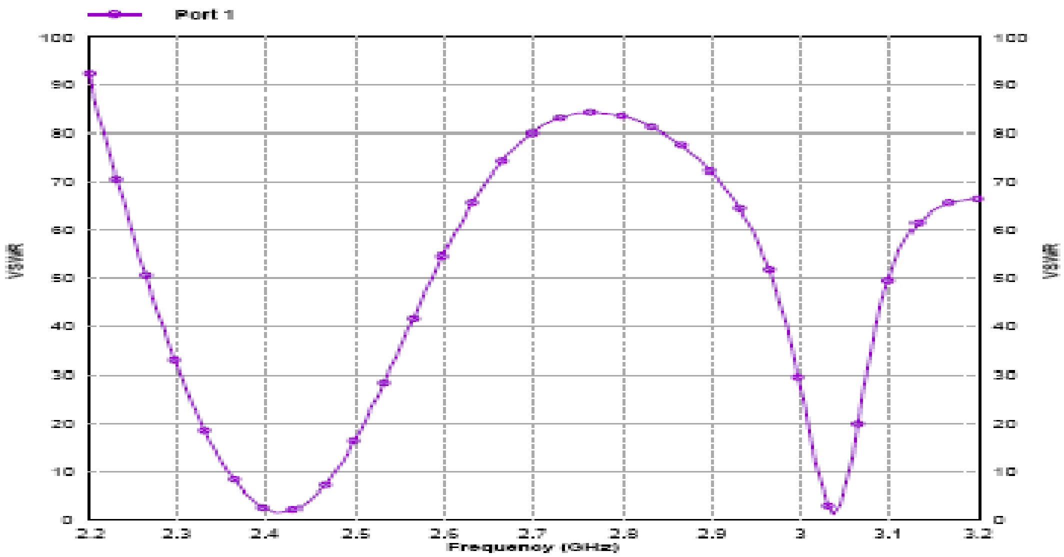


Figure 5.4(b) VSWR of Micr. patch antenna is 1.393 at =2.419 GHz and 1.114 at =3.04 GHz

2. Random Optimization:

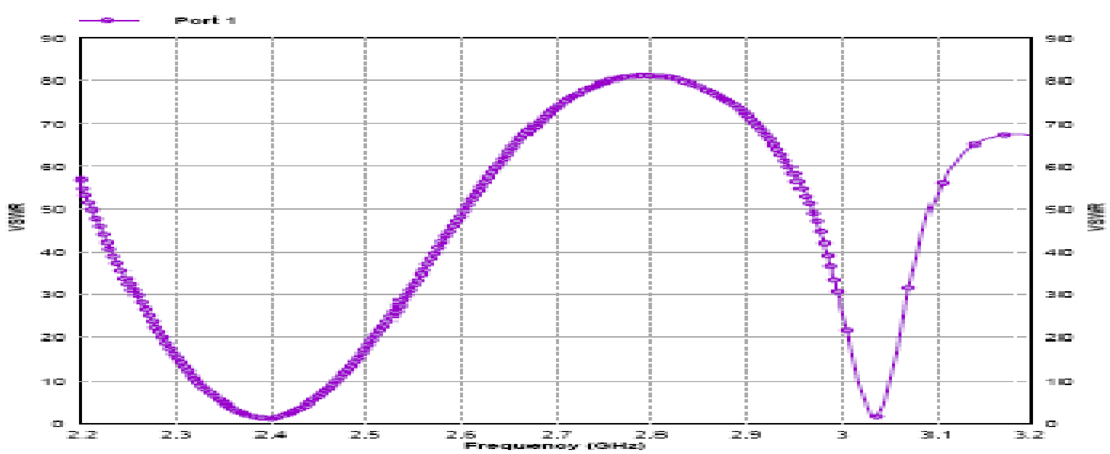


Figure 5.4(b) VSWR of Microstrip patch antenna is 1.162 at =2.393 GHz and 1.718 at =3.04

3. Powell Opimization :

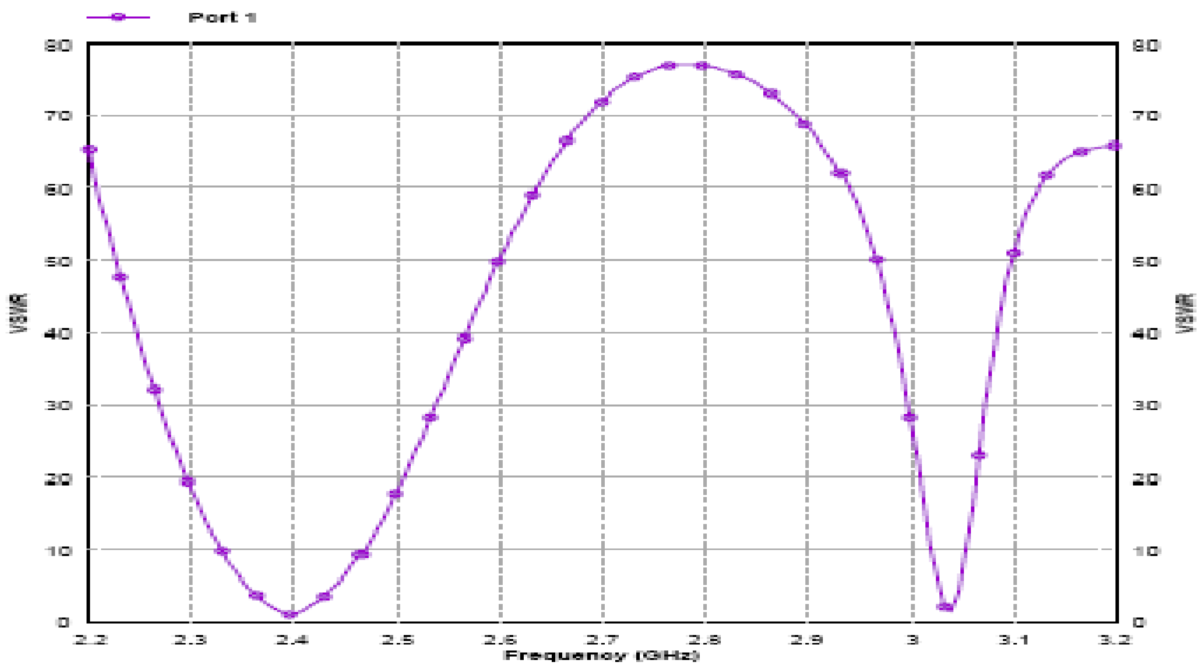


Figure 5.4(c) VSWR of Microstrip patch antenna is 1.018 at =2.4 GHz and 1.484 at =3.04

4. Genetic Algorithm Optimization:

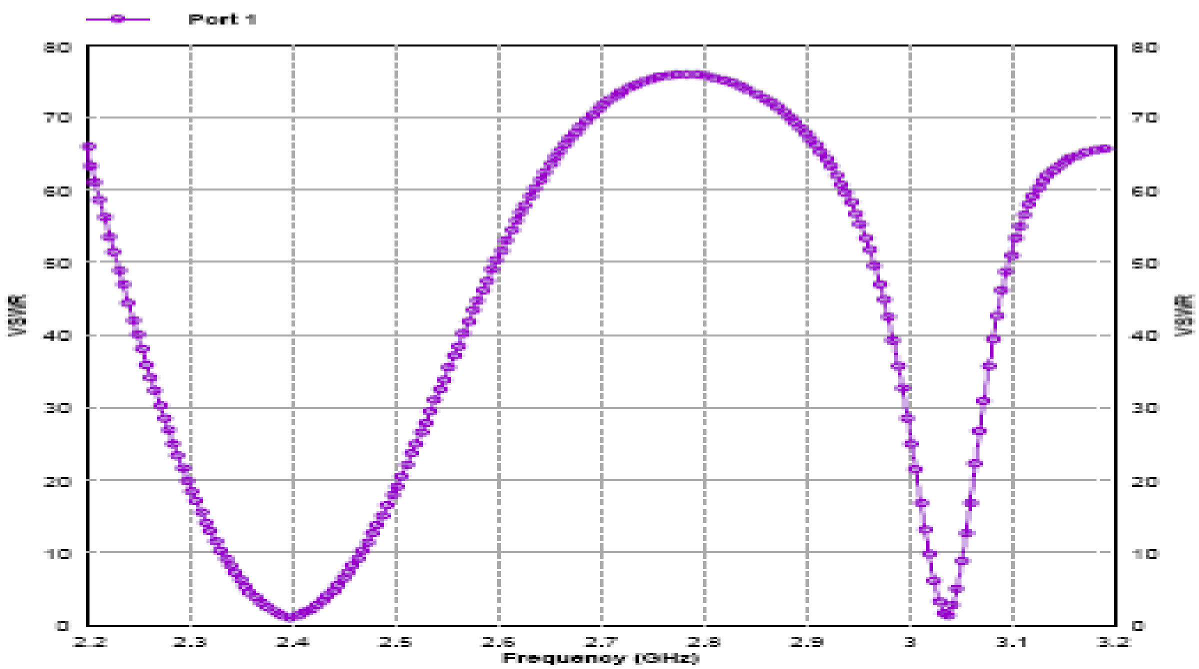


Figure 5.4(d) VSWR of Mico patch antenna is 1.05 at =2.399GHz and 1.042 at =3.038GHz

5. Adaptive EM Optimizer:

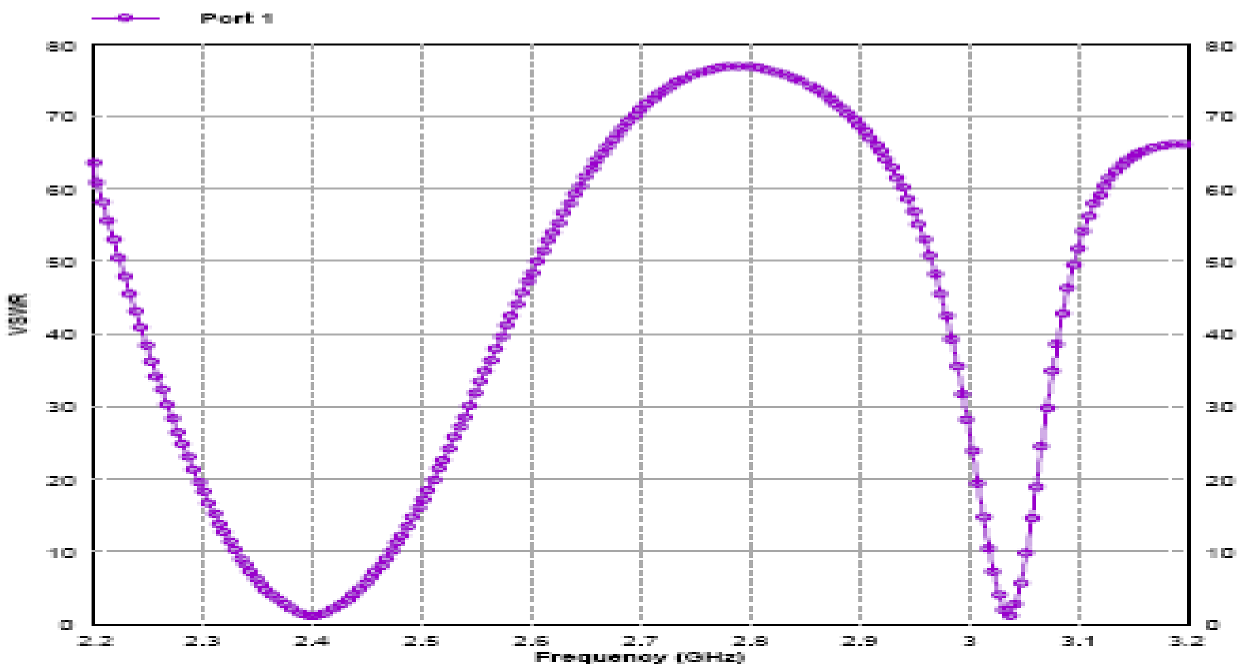


Figure 5.4(b) VSWR of Mico patch antenna is 1.042 at =2.402 GHz and 1.063 at =3.038GHz

5.4.4 Input Impedance:

As has been stated in Chapter 2, we expect pure real impedance at frequencies where the patch resonates, that is, where the patch is designed to radiate. As a result, the input impedance plot in are blow shows the theoretical result, optimization, around the desired radiating frequency, sufficient reactance cancellation can only occur inside a narrow bandwidth. In addition, one needs to match the resonant resistance with the characteristic impedance of the feed line. A small antenna can be tuned to resonate with an appropriate addition of reactance, or it can be made to self-resonate so that the reactance cancellation at resonance happens naturally in the antenna structure. Since adding external reactance for this purpose increases the power loss and it also requires extra space, it is advisable to follow the second alternative

1. **Theoretical result (IE3D):**

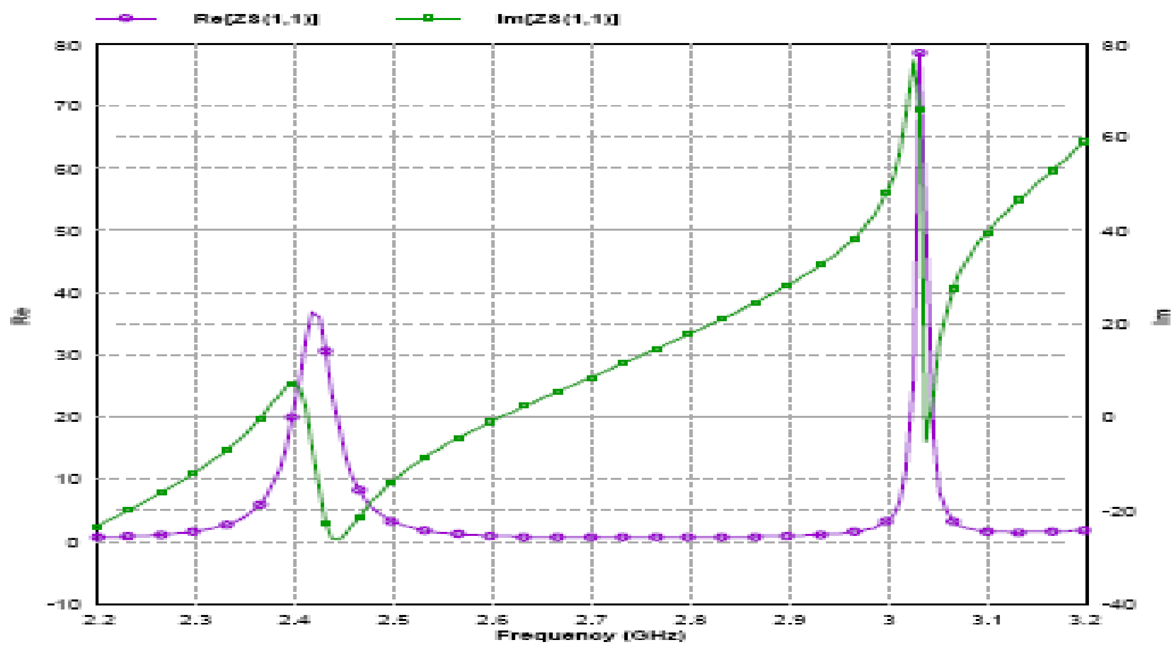


Figure 5.5(a) Input Impedance at 2.418 GHz is 37.8Ω *& at 3.04 GHz is 52.04* Ω

2. Random Optimization:

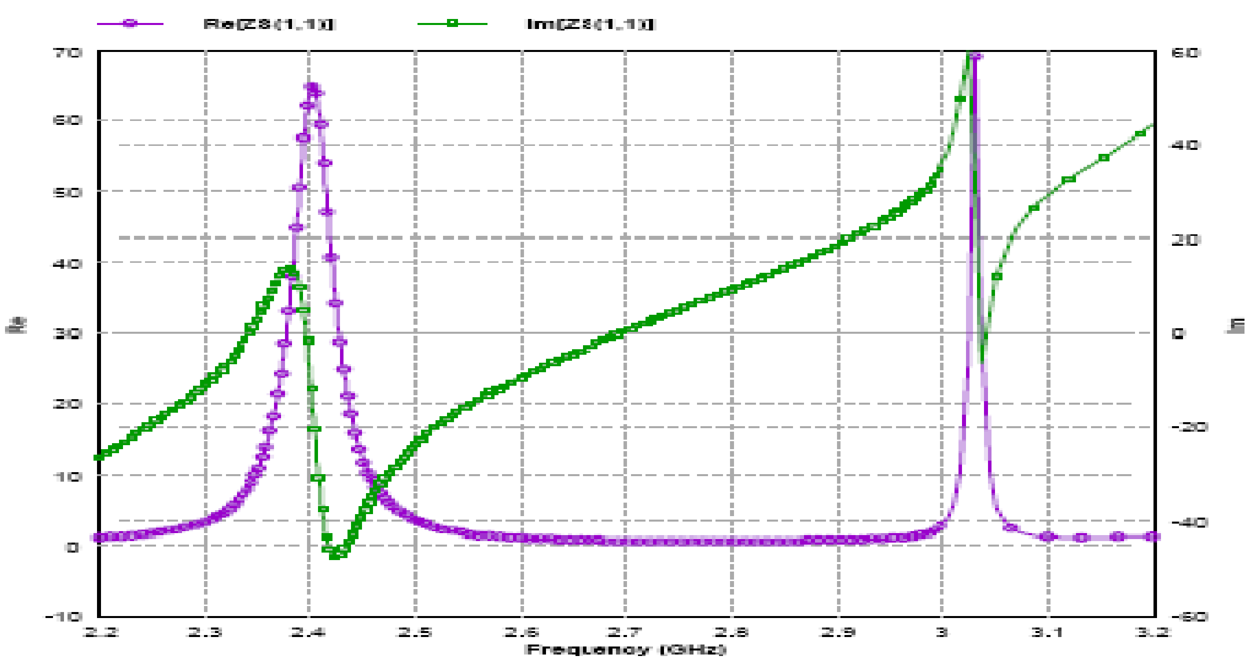


Figure 5.5(b) Input Impedance at 2.396 GHz is 55.28Ω *& at 3.04 GHz is 34.64* Ω

3. Powell Opimization :

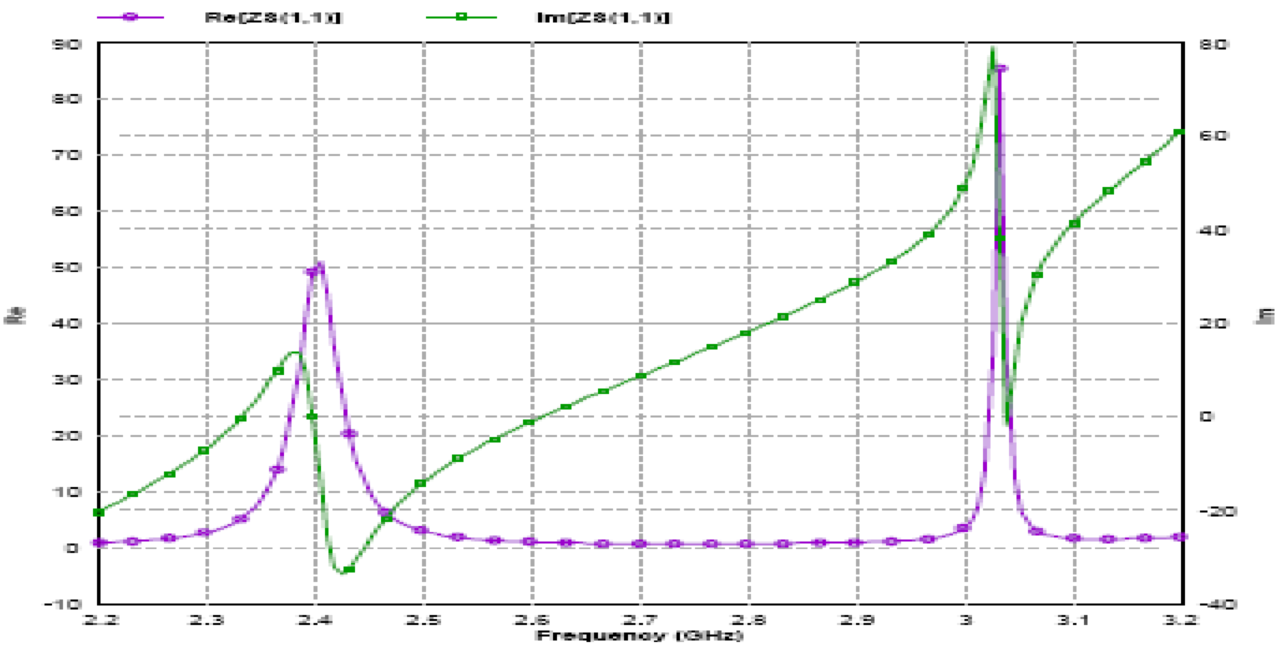


Figure 5.5(c) Input Impedance at 2.4 GHz is 49.11 *& at 3.04 GHz is 38.64* Ω

4. Genetic Algorithm Optimization:

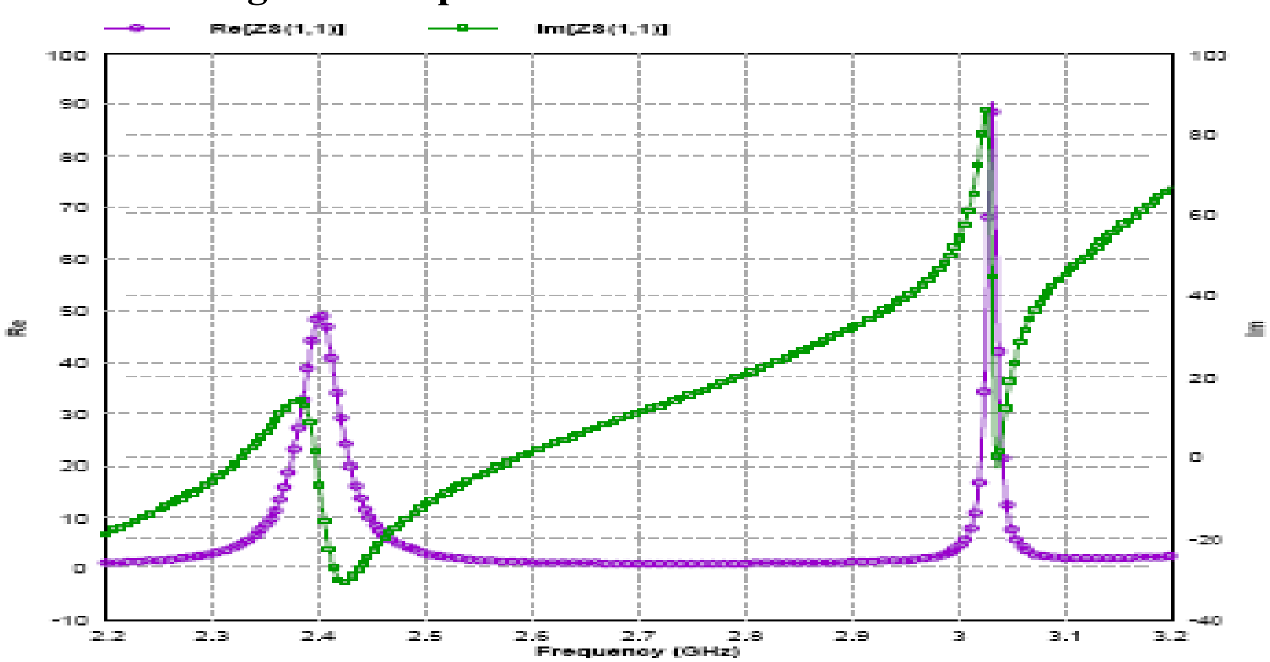


Figure 5.5(d) Input Impedance at 2.4 GHz is 48.21 *& at 3.04 GHz is 44.64* Ω

5. **Adaptive EM Optimizer:**

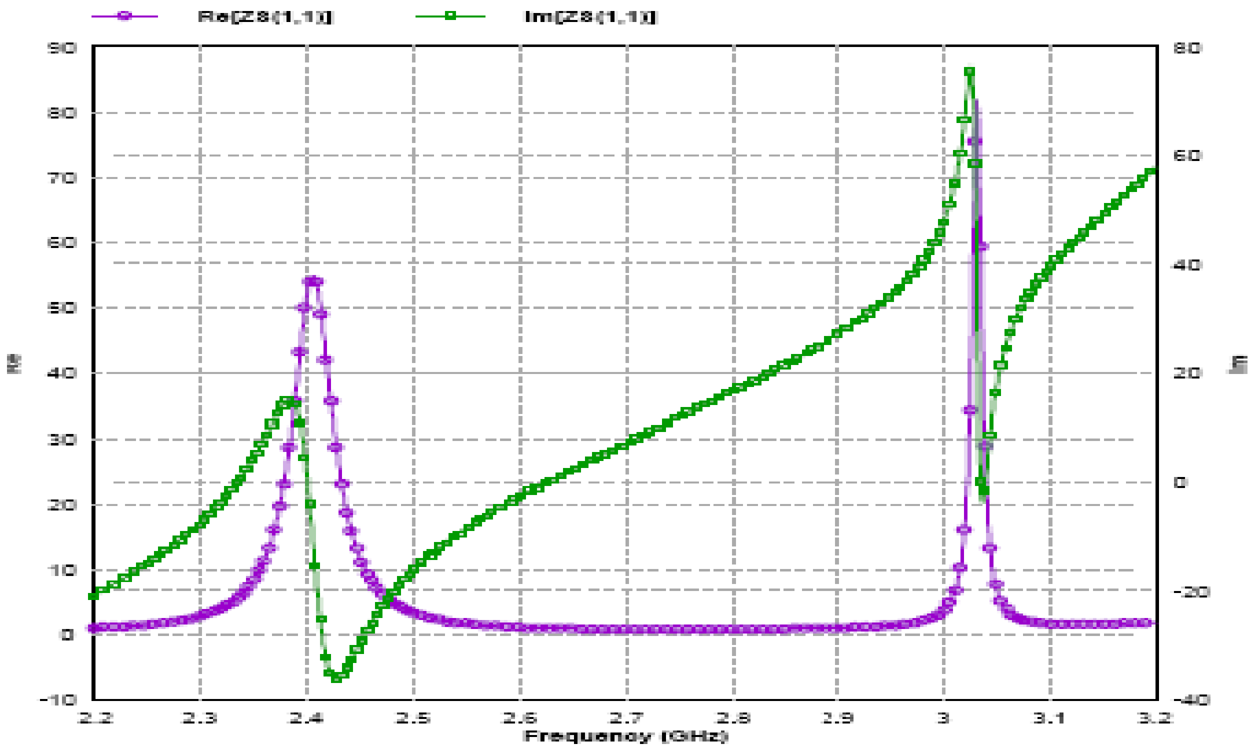


Figure 4.6(e) Input Impedance at 2.4 GHz is 50.01 *& at 3.04 GHz is 42.64* Ω

5.5 Compression between the Theoretical, Random Optimization, Powel Optimization, Genetic Algorithm Optimization and Fast EM Optimization results of dual band antenna:-

Antenna Parameter	**Theoretical result (IE3D**	**Random Optimization:**	**Powell Opimization**	**Genetic Algorithm Optimization**	**Adaptive EM Optimizer:**
Frequency (f_1) [GHz] And Return loss(dB)	2.419GHz (-15.63 dB)	2.396GHz (-22.45dB)	2.4GHz (-40.91dB)	2.4GHz (-40.95dB)	2.4GHz (-33.09dB)
Frequency (f_2) [GHz] And Return loss(dB)	3.04 GHz (-25.33dB)	3.04GHz (-11.54dB)	3.04GHz (-14.54dB)	3.04GHz (-15.05dB)	3.3038GHz (-30.35dB)
VSWR for f_1	1.393	1.162	1.018	1.05	1.042
VSWR for f_2	1.114	1.718	1.484	1.041	1.063
Impedance for f_1(Ω)	37.8	55.28	49.11	48.21	50.01
Impedance for f_2(Ω)	52.04	34.64	38.64	44.85	42.63

5.6 The Versatile U-Slot Patch Antenna:

U-slot microstrip patch antennas were originally developed for bandwidth broadening applications. Recently, it was found that the U-slot technique can also enable the patch antenna to perform other functions, including: dual-band and
tri-band operations**.**

AS A WIDEBAND LINEARLY POLARIZED ANTENNA

While the antenna is known to provide more than 30% impedance bandwidth when an air substrate thickness of about 0.08λo is used, less well known is that a thinner antenna will
also provide sufficient bandwidth for several applications. For example, in Advanced Mobile Phone Service (AMPS), about 8.1% bandwidth is sufficient. Likewise, in Global System for Mobile Communications (GSM), only 8.7% bandwidth is needed. While such bandwidths cannot be realized by the traditional patch antenna, we shall show that it can be realized by the U-slot patch antenna of only 0.03λothick, which has 10.6% bandwidth.

5.6.1 Geometry of proposed Antenna

AS A DUAL-BAND LINEARLY POLARIZED ANTENNA

Most of the studies of the U-slot patch antenna were concerned with its broad band capabilities. However, since the U-slot introduces another resonance, it is clear that a suitable Design will yield dual-band behavior. The dimensions of a dual band U-slot patch antenna are presented in Table I as an example, and the simulated return loss is shown in below.

DIMENSIONS OF DUAL-EAND U-SLOT ANTENNA

Parameters	W	L	H	U_x	U_y	U_t	U_d	d
Dimensions /mm	62	47	4	28	14	0.6	6	23.5

Table 5.3 The dimensions of a dual band U-slot patch antenna are presented

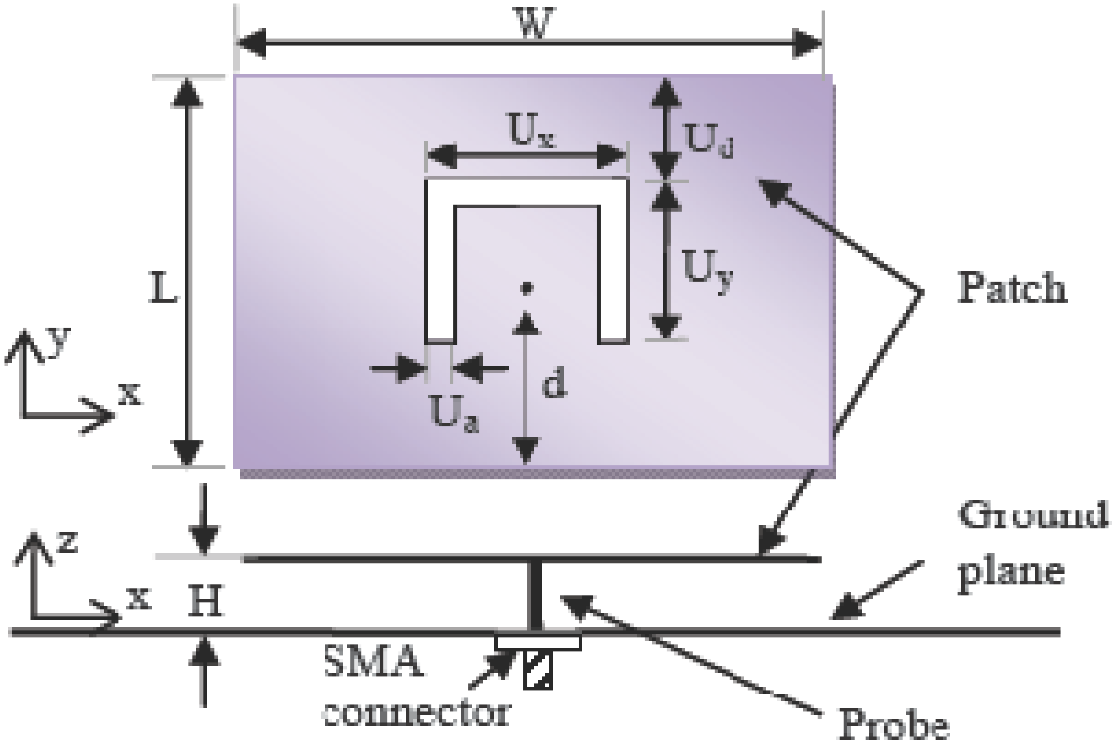


Fig.5.6 Geometry of the U-Slot patch antenna

5.6.2 Simulation Setup and Result

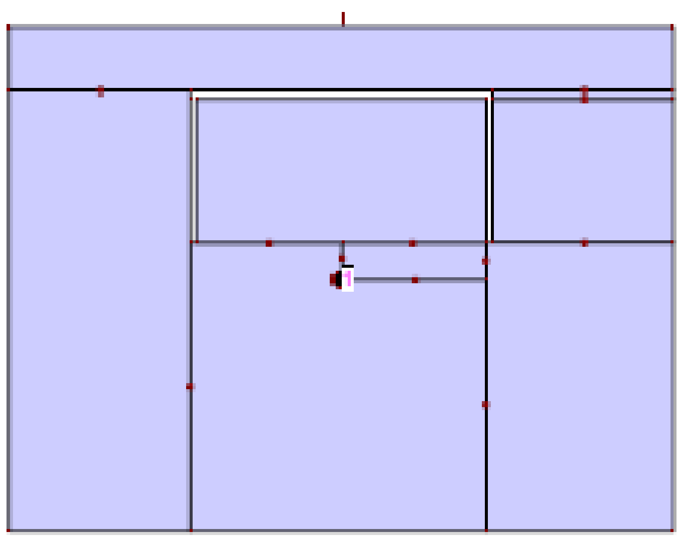


Fig 5.7 Simulation diagram of Patch in IE3D

1. Return loss and Antenna Bandwidth

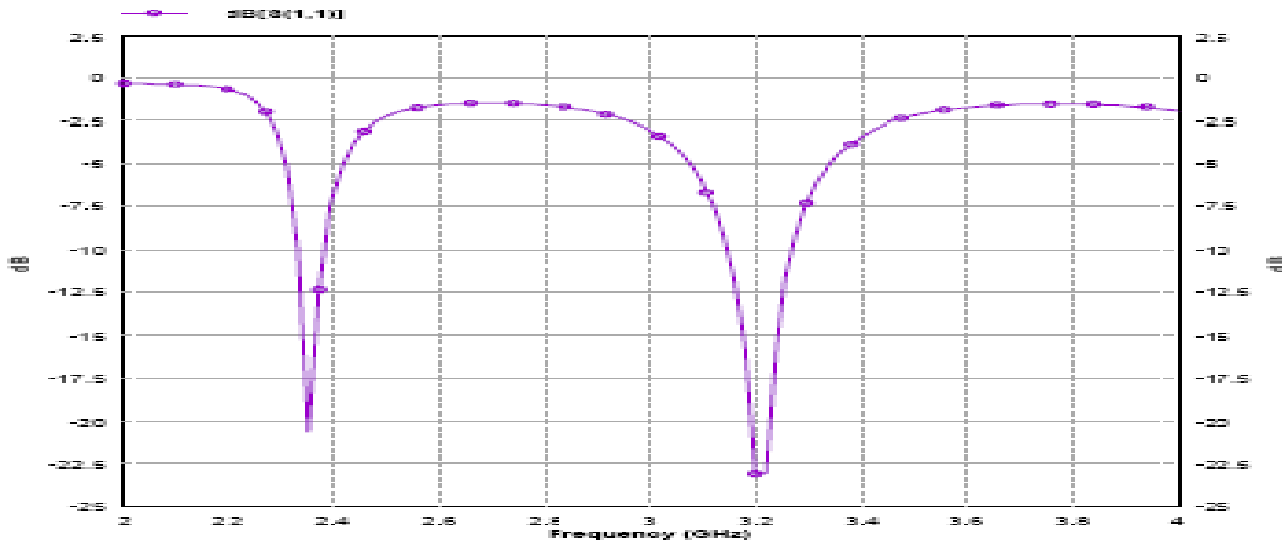


Figure 5.8 Return loss is -20.64dB (2.36 GHz, BW 52MHz)
and Return loss is -23.05 dB (3.22 GHz, BW 1.28 GHz)

2. Input Impedance :

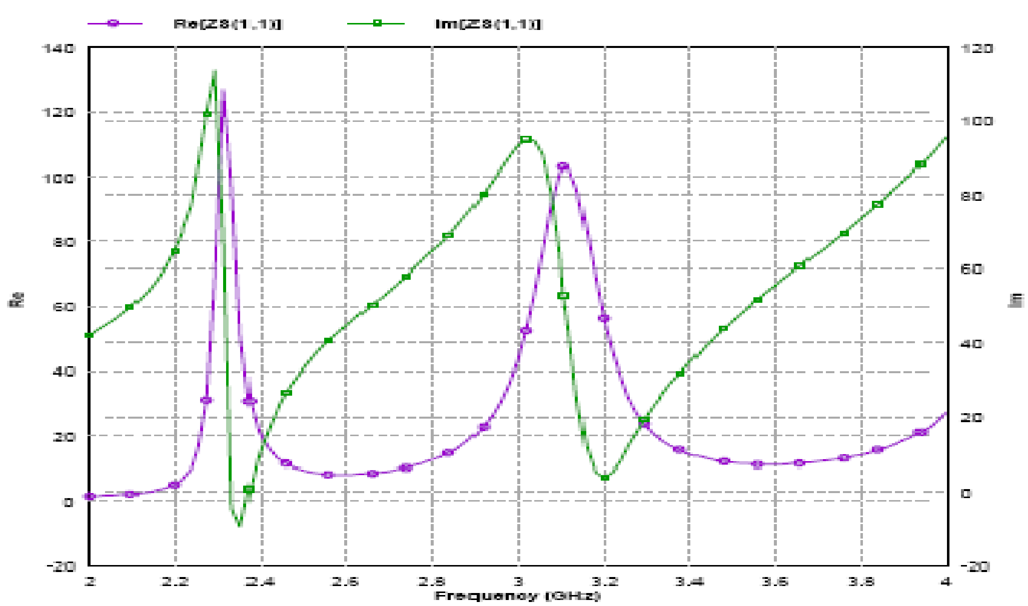


Figure 5.9 Input Impedance at 2.36 GHz is 52.12 Ω *& at 3.22 GHz is 35.04* Ω

3. VSWR Plot

Voltage standing wave ratio (VSWR) of Microstrip antenna shown in below figure shows the theoretical result and the optimization of the patch. In case of Microstrip patch antenna the value of VSWR is always less than 2. At *) VSWR of Microstrip Patch antenna is 1.205 at =2.36 GHz and 1.151 at =3.22 GHz*

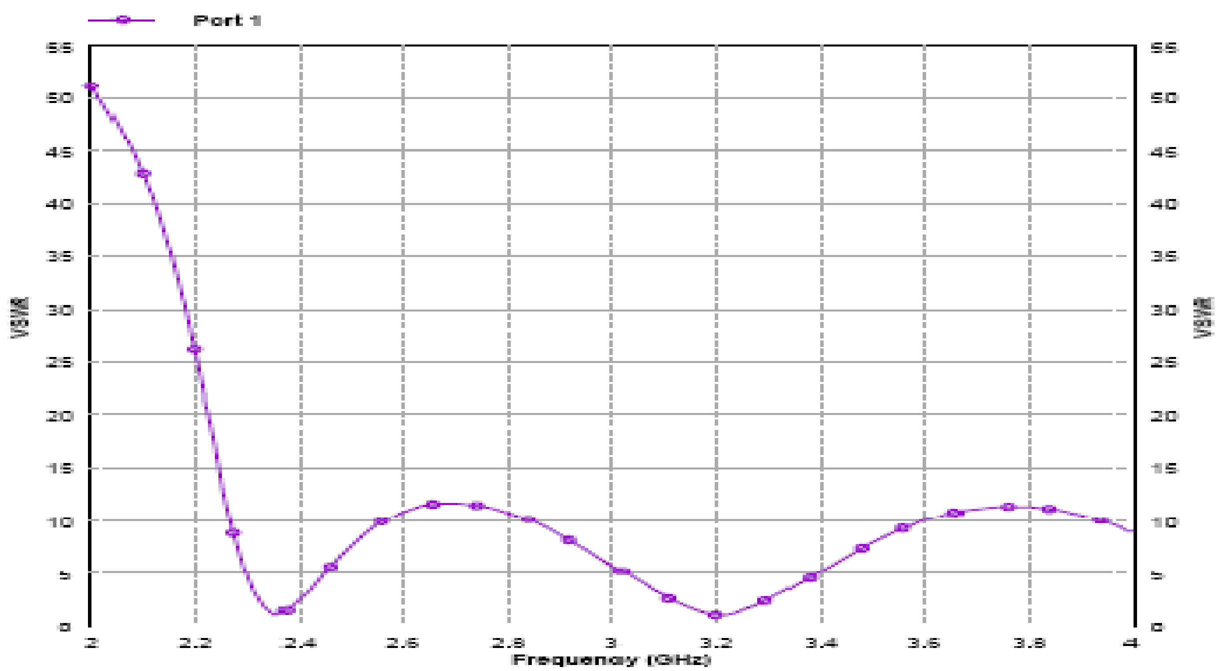
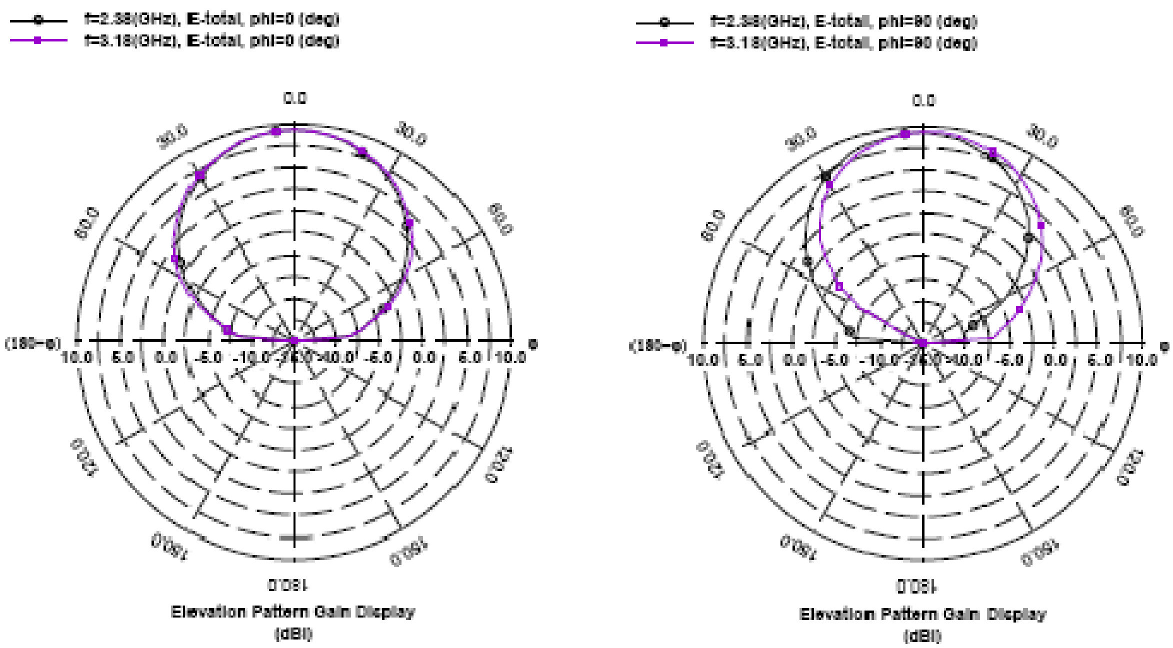


Figure 5.10 VSWR of Micr. Patch antenna is 1.205 at =2.36 GHz and 1.151 at =3.22 GHz

4. Radiation pattern plot

A Microstrip patch antenna radiates normal to its patch surface. The elevation pattern for Φ=0 and Φ=90 degrees would be important. Below Figure show the 2D radiation pattern of the antenna at the designed frequency for Φ=0 and Φ=90 degrees.



5. Gain vs. Freque ncy Plot

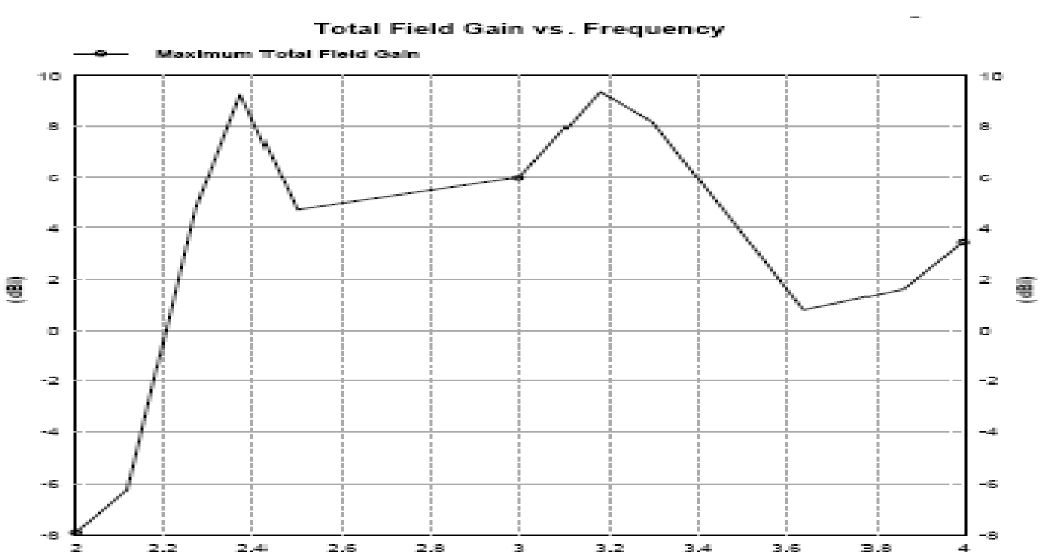


Figure 5.11 Gain of the patch is 8.45 dB at f=2.36 GHz And 9.12 dB at f= 3.22GHz

CHAPTER 6 CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

Two aspects of Microstrip antennas have been studied in this thesis. The first aspect is the design of typical rectangular Microstrip antenna and the second is the design of dual band Microstrip antenna. A simple and efficient technique of inset method has been introduced for an impedance matching improvement of the antennas. Main concern of the thesis is to study of Dual band patch antenna using different techniques and frequency ratio of the Microstrip antenna. The dual band Microstrip antenna is a more conventional approach for the implementation of a broadband antenna and for satellite communication where the low frequency ratio is used. Initially, single element rectangular Microstrip antenna is designed to operate at frequency 2.4 GHz. And then, the dual band Microstrip antenna is designed to resonate at frequency range 2.4 GHz to 3.08 GHz. The dual band antenna shows that with correct selection of slot dimensions and positions, a dual frequency response can be achieved, while still allowing the use of a planar feed.

The second and very important work is done in this thesis is to implement the single and dual band Microstrip antenna using Optimization techniques IE3D. The design optimization of a single and dual band rectangular patch antenna has been implemented using Random Optimization, Powell Opimization, Genetic Algorithm Optimization, Adaptive EM Optimizer techniques.

6.2 Suggestions for Future Work

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

The design optimization of a single and dual band rectangular patch antenna has been implemented combining an efficient evolutionary optimization method (PSO) with a standard electromagnetic simulator (IE3D) using the interfacing between the IE3D and PSO (MATLAB). The accuracy, robustness and ease of implementation of this method validate its potential application in patch antenna design. This method can also be effectively used in the design of various complex microwave and millimeter-wave circuits.

At present facility for fabrication of patch Antenna is not available in our institute; the same work will be performed latter. The simulated, optimized and experimental results will be compared.

Using the dual frequency Microstrip antenna as a basis, the circular dual frequency Microstrip antenna can be developed. For using the same INSET feeding technique, in terms of wavelength, between the corresponding slots in radiating edge, the “spokes” of the antenna are arranged around the circumference.

Using the shorting post and changing the slot position in this patch to develop the WLAN concept (2.4 GHz & 5.2 GHz frequency) and also this patch can be used in satellite communication where the low frequency ratio patch is used.

The first improvement would be to endow the PSO algorithm with a memory for the Fitness of a certain antenna configuration. Since the structures being used in this thesis are relatively small, the penalty for evaluating the same configuration multiple times does not degrade the overall performance significantly. For larger structures, it would however not be acceptable to reevaluate multi-hour runs.
It would be interesting to include an implementation of the genetic algorithm and thus be able to compare their progress. An elaborate investigation of how the PSO parameters affect this particular antenna optimization is also of interest.

Appendix

MATLAB Program for Rectangular Patch design

```
%%%%%%%% DESIGN  FOR  RECTANGULAR PATCH %%%%%%%
clear all;

close all;

epsilon=input('enter epsilon');

  rin0=input('enter the required resistance');

rfreq1=input ('radiation frequency');

rfreq=rfreq1*10^9;

 h=input ('enter the thickness of the substrate');

w0=input ('enter the width of the microstrip feed line');

 c=2.4*10^10;  w=c/((2*rfreq)*((epsilon+1)/2)^(0.5));

epsilonreff=((epsilon+1)/2)+((epsilon-1)/2)*((1+12*(h/w)))^(-0.5);

deltaL=h*0.412*(epsilonreff+0.3)*((w/h)+0.264)/((epsilonreff-0.258)*(w/h+0.8));

Leff=c/(2*rfreq*(epsilonreff)^(0.5));

L=Leff-2*deltaL;

%........INSET FEEDING..........

lamda_o=c/rfreq            %wavelength

 ko=(2*pi)/lamda_o;

A=(1/(120*(pi^2)));
F1=0;
```

```
for      theta=[0:1:180]*pi/180

          z=ko*L*sin(theta);

         J = besselj(0,z);

 I =  (((sin((ko*w/2)*cos(theta)))/cos(theta))*((sin((ko*w/2)*cos(theta)))/cos(theta)))*J*((sin(theta))^
3)*(pi/180);

  F1=I+F1;                          %current (I1=F1)

end

g12=F1*A;

if (w > lamda_o)

g1=(1/120)*(w/lamda_o);

end

 if (w < lamda_o)

  g1=(1/90)*((w/lamda_o)^2);

end

 Rin=(1/(2*(g1+g12)));

  if ((w0/h) <= 1)

  Z=(60*(epsilonreff)^(-0.5))*log(((8*h)/w0)+(w0/4*h));

end

 if ((w0/h) > 1)    Z=(120*pi)/((epsilonreff)^(0.5)*((w0/h)+1.393+0.667*log((w0/h)+1.444)));

end

 Zc=Z;                              %calculation for Microstrip line width

Y01=(L/pi).*acos(rin0/Rin)^(0.25);         % calculation for inset depth
```

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