ENHANCEMENT OF BANDWIDTH AND GAIN OF A RECTANGULAR MICROSTRIP PATCH ANTENNA

A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Technology
in
Electronics and Communication Engineering
By

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CERTIFICATE

This is to certify that the thesis entitled, "**ENHANCEMENT OF BANDWIDTH AND GAIN OF A RECTANGULAR MICROSTRIP PATCH ANTENNA**" submitted by **Mr. V. Mohan Kumar** and **Mr. N. Sujith** in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in **ELECTRONICS AND COMMUNICATION and ELECTRONICS AND INSTRUMENTATION respectively** at the National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

Date:

Dr. S. K. BEHERA,
Associate Professor.

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V. Mohan Kumar
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ABSTRACT

In this project, method of moments based IE3D software is used to design a Microstrip Patch Antenna with enhanced gain. The aim of the project is to design a rectangular Microstrip Patch Antenna with enhanced gain and bandwidth and study the effect of antenna dimensions Length (L), Width (W) and substrate parameters relative Dielectric constant (ε_r), substrate thickness on antenna gain and bandwidth. 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 simulated by using IE3D simulator. And Patch antenna is realized as per design requirements.

A wideband phi-shape microstrip patch antenna has been designed. The return loss is below −10 dB from 4.45 GHz to 7.4 GHz except at 5.1GHz with a bandwidth of 48%.The antenna is thin and compact which makes it easily portable. A maximum gain of 8.77dB achieved at 4.7 GHz frequency. The VSWR parameter was found to be less than 2 within the operating frequency range. It can be used for wireless Local Area Network application in the frequency range 5.2 to 5.8 GHz.

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CHAPTER 1

INTRODUCTION

Communication between humans was first by sound through voice. With the desire for slightly more distance communication came, devices such as drums, then, visual methods such as signal flags and smoke signals were used. These optical communication devices, of course, utilized the light portion of the electromagnetic spectrum. It has been only very recent in human history that the electromagnetic spectrum, outside the visible region, has been employed for communication, through the use of radio. One of humankind's greatest natural resources is the electromagnetic spectrum and the antenna has been instrumental in harnessing this resource.

1.1 Objective of Project

Microstrip patch antenna is used to send onboard parameters of article to the ground while under operating conditions. The aim of the thesis is to design rectangular Microstrip Patch Antenna with enhanced gain and bandwidth and study the effect of antenna dimensions Length (L), Width (W) and substrate parameters relative Dielectric constant (εr), substrate thickness (t) on the Radiation parameters of Bandwidth and Beam-width.

1.2 Antenna Characteristics

An antenna is a device that is made to efficiently radiate and receive radiated electromagnetic waves. There are several important antenna characteristics that should be considered when choosing an antenna for your application as follows:

- Antenna radiation patterns
- Power Gain

• Directivity

• Polarization

1.3 Microstrip Patch Antenna

In its 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.1.1

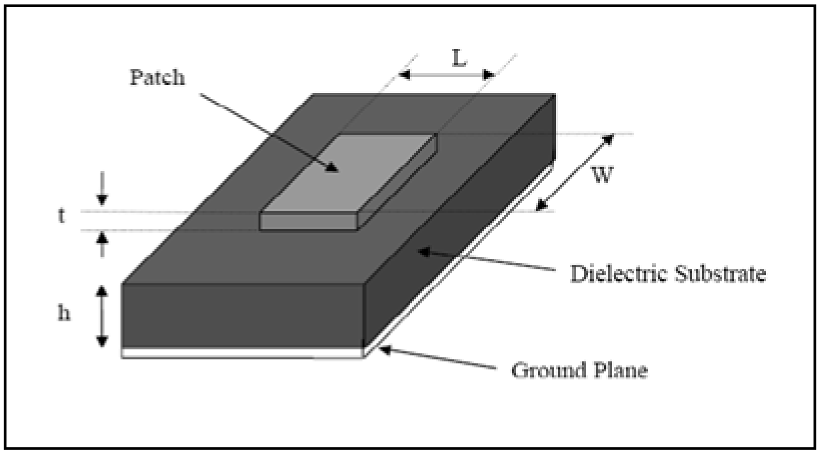


Figure 1.1: Microstrip patch antenna

The patch is normally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

In order to simplify analysis and performance estimation, generally square, rectangular, circular, triangular, and elliptical or some other common shape patches are used for designing a microstrip antenna.

For a rectangular patch, the length L of the patch is usually $0.3333\lambda o< L < 0.5\ \lambda o$, where λo is the free-space wavelength. The patch is selected to be very thin such that $t << \lambda o$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\ \lambda o \leq h \leq 0.05\ \lambda o$. The dielectric constant of the substrate (εr) is typically in the range $2.2 \leq \varepsilon r \leq 12$.

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good performance of antenna, a thick dielectric substrate having a low dielectric constant is necessary since it provides larger bandwidth, better radiation and better efficiency. However, such a typical configuration leads to a larger antenna size. In order to reduce the size of the Microstrip patch antenna, substrates with higher dielectric constants must be used which are less efficient and result in narrow bandwidth. Hence a trade-off must be realized between the antenna performance and antenna dimensions.

1.4 Advantages and Disadvantages

Microstrip patch antennas are mostly used in wireless applications due to their low-profile structure. Therefore they are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc...

Some of the principal advantages are given below:

• Light weight and less volume.

• Low fabrication cost, therefore can be manufactured in large quantities.

• Supports both, linear as well as circular polarization.

• Low profile planar configuration which can be easily made conformal to host surface.

• Can be easily integrated with microwave integrated circuits (MICs).

• Capable of dual and triple frequency operations.

• Mechanically robust when mounted on rough surfaces.

Microstrip patch antennas suffer from more drawbacks as compared to conventional antennas.

Some of their major disadvantages are given below:

- Narrow bandwidth
- Low efficiency
- Low Gain
- Low power handling capacity.
- Surface wave excitation
- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antennas

Microstrip patch antennas have a very high antenna quality factor (Q). It represents the losses associated with the antenna where a large Q leads to narrow bandwidth and low efficiency.

Q can be decreased 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.

1.5 Different Feed Techniques

Feed Techniques

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.

Different Types of Feeding Techniques

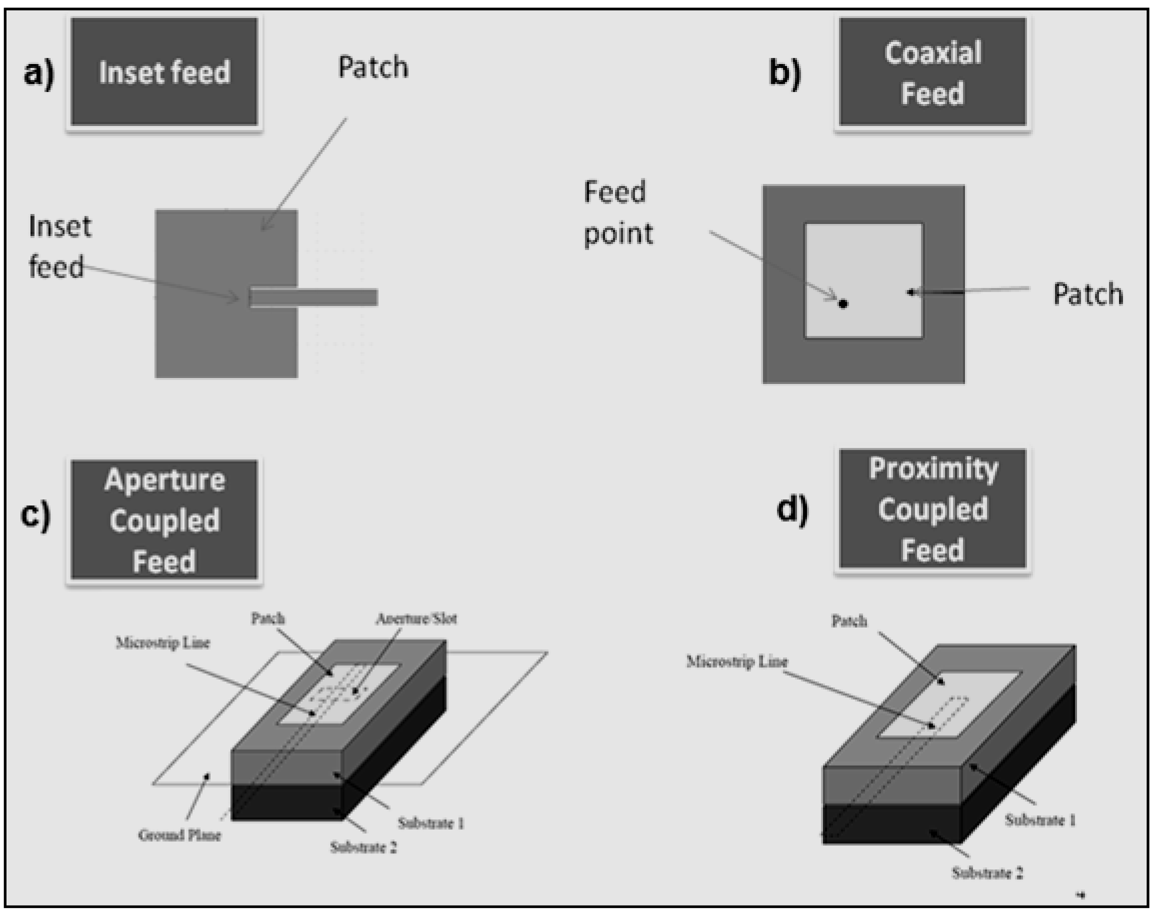


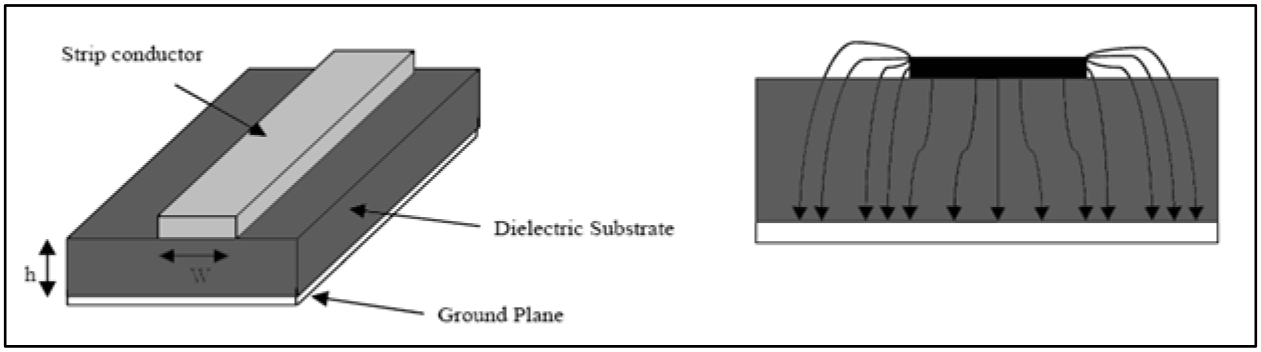
Figure 1.2: Comparison of different feed techniques

characteristics	Microstrip line feed	Coaxial feed	Aperture coupled feed	Proximity coupled feed
Spurious feed radiation	More	More	Less	Minimum
Reliability	Better	Poor due to soldering	Good	Good
Ease of fabrication	Easy	Soldering and Drilling needed	Alignment Required	Alignment Required
Impedance matching	Easy	Easy	Easy	Easy
Bandwidth	2-5%	2-5%	21%	13%

Table 1.1: Comparison of different feed techniques

1.6 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. The microstrip is essentially a non-homogeneous line of two dielectrics, normally the substrate and air.



(a) (b)

Figure 1.3(a) Microstrip Line (b) Electric Field Lines

Hence, as shown in Figure.1.3 (b), most of the electric field lines lies in the substrate and parts of some lines are in air. As a result, this transmission line do not support pure transverse-electromagnetic 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 ($\varepsilon reff$) must be obtained in order to account for the fringing and the wave propagation in the line. The value of $\varepsilon reff$ is little less then εr because the fringing fields around the edge of the patch are not confined in the dielectric substrate but are also spread in the air as shown in Figure above. The expression for $\varepsilon reff$ can be given as:

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

Where ε_{reff} = Effective dielectric constant

ε_r = Dielectric constant of substrate

H = Height of dielectric substrate

W = Width of the patch

Consider Figure 1.4, which shows a rectangular microstrip patch antenna of length L, width W lying on a substrate of height h. The co-ordinate axis is selected in such a way that the length is along the x axis direction, width is along the *y axis* direction and the height is along the *z axis* direction.

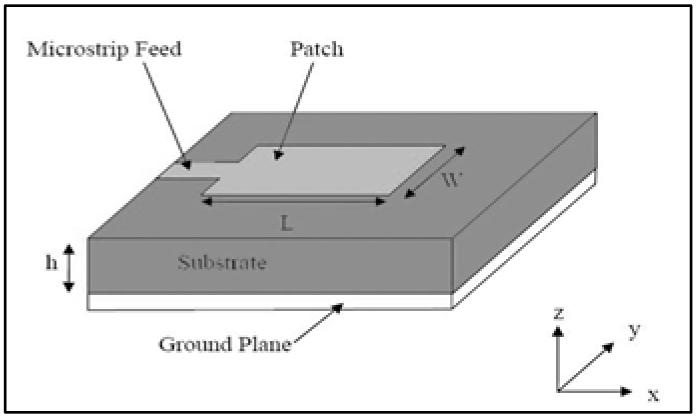
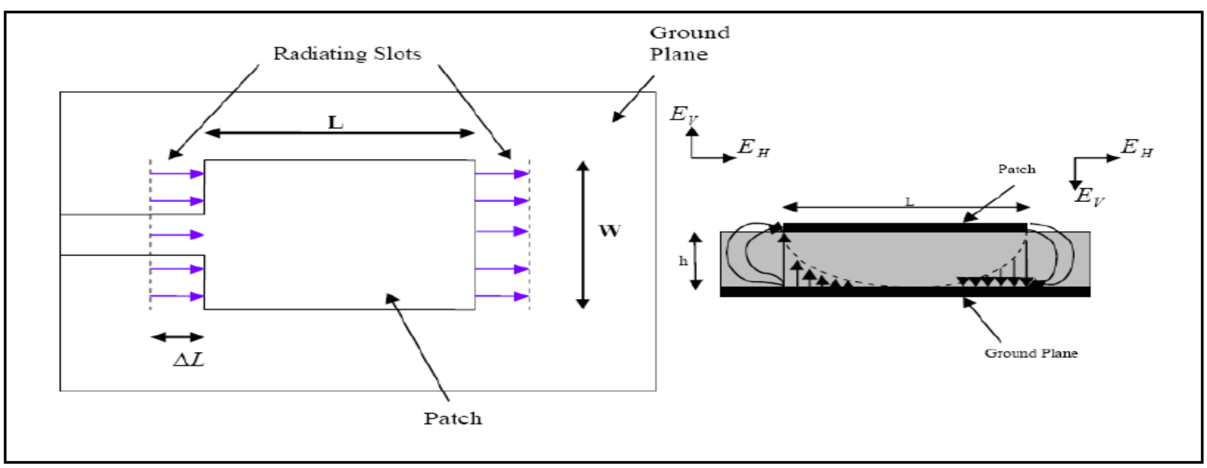


Figure 1.4: Microstrip Patch Antenna

In order to operate in the TM_{10} mode, the length of the patch must be slightly less than $\lambda/2$ where λ is the wavelength in the dielectric medium and is equal to $\lambda o/\sqrt{\varepsilon reff}$ where λo 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 difference along the width of the patch. In the Figure 1.5, the microstrip patch antenna is shown by two slots and 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.



(a) (b)

Figure 1.5 :(a) Top View of Antenna (b) Side View of Antenna

It is shown in Figure 1.5.b 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 λ/2 long and hence they nullify each other in the broadside direction. The tangential components 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 λ/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 as:

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

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

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

For a given resonance frequency fo, the effective length is given by as:

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

For a rectangular Microstrip patch antenna, the resonance frequency for any TM_{mn} mode is given by as:

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

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

For efficient radiation, the width W is given as;

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

1.7 Organization of the Thesis

An introduction to microstrip antennas was given in Chapter I. Apart from the advantages and disadvantages, the various feeding techniques and models of analysis were listed.

Chapter II deals with the Basic parameters that are considered while designing of Microstrip patch antenna. The theory of radiation, various parameters and design aspects were discussed.

Chapter III provides the design and parametric study of U-slotted and E-shaped Microstrip patch antenna with enhanced gain and bandwidth.

Chapter IV provides the design and development of phi shaped microstrip antenna with more enhanced gain and bandwidth compared to previous U-slotted and E-shape.

Chapter V gives the Conclusion to this project and suggests the future prospects.

CHAPTER 2

Properties of a Basic Microstrip Patch

A microstrip or patch antenna is a low profile antenna that has a number of advantages over other antennas it is lightweight, low cost, and easy to integrate with accompanying electronics. While the antenna can be 3D in structure (wrapped around an object, for example), the elements are usually flat; hence their other name, planar antennas. Note that a planar antenna is not always a patch antenna.

The figure 2.1 shows a patch antenna in its basic form: a flat plate on a ground plane. The center conductor of a coax serves as the feed probe to couple electromagnetic energy in and/or out of the patch. The electric field distribution of a rectangular patch in its fundamental mode is also shown

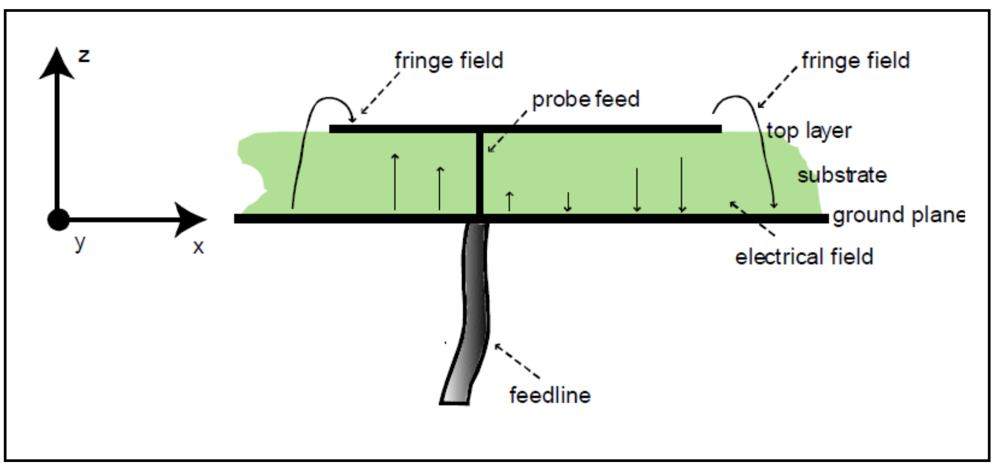


Figure 2.1: Basic Microstrip patch antenna with probe feeding

The electric field is zero at the center of the patch, maximum (positive) at one side, and minimum (negative) on the opposite side. It should be mentioned that the minimum and maximum continuously change side according to the instantaneous phase of the applied signal. The electric field does not stop abruptly at the patch's periphery as in a cavity rather, the fields extend the outer periphery to some degree. These field extensions are known as fringing fields and cause the patch to radiate. Some popular analytic modeling techniques for patch antennas are based on this leaky cavity concept. Therefore, the fundamental mode of a rectangular patch is often denoted using cavity theory as the TM_{10} mode.

Since this notation frequently causes confusion, we will briefly explain it. TM stands for transversal magnetic field distribution. This means that only three field components are considered instead of six. The field components of interest are: the electric field in the z direction, and the magnetic field components in x and y direction using a Cartesian coordinate system, where the x and y axes are parallel with the ground plane and the z axis is perpendicular.

In general, the modes are designated as TMnmz. The z value is mostly omitted since the electric field variation is considered negligible in the z axis.

Hence TMnm remains with n and m the field variations in x and y direction. The field variation in the y direction (impedance width direction) is negligible; thus m is 0. And the field has one minimum to maximum variation in the x direction (resonance length direction); thus n is 1 in the case of the fundamental. Hence the notation TM_{10}.

2.1 Dimensions

The resonant length determines the resonant frequency and is about l/2 for a rectangular patch excited in its fundamental mode. The patch is, in fact, electrically a bit larger than its physical dimensions due to the fringing fields. The deviation between electrical and physical size is mainly dependent on the PC board thickness and dielectric constant.

A better approximation for the resonant length is:

$$L \approx 0.49\ \lambda_d = 0.49\ \frac{\lambda_0}{\sqrt{\varepsilon_r}}.$$

This formula includes a first order correction for the edge extension due to the fringing fields, with:

· L = resonant length

· λ_d = wavelength in PC board

· λo = wavelength in free space

· ε_r = dielectric constant of the PC board material

Other parameters that will influence the resonant frequency:

· Ground plane size

· Metal (copper) thickness

· Patch (impedance) width

2.2 Impedance Matching

Looking at the current (magnetic field) and voltage (electrical field) variation along the patch, the current is maximal at the center and minimal near the left and right edges, while the electrical field is zero in the center and maximal near the left and minimal near the right edges. The figures below clarify these quantities.

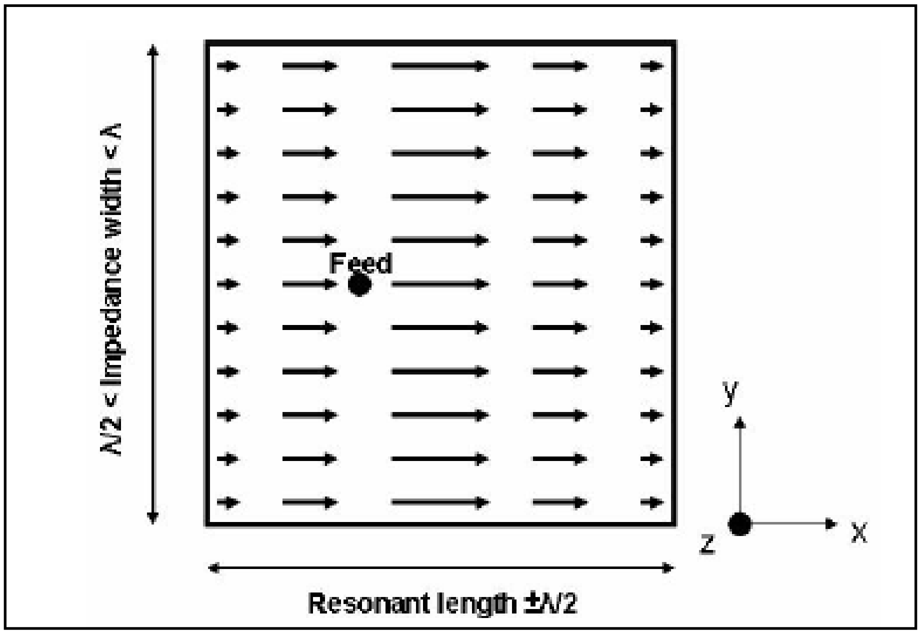


Figure 2.2: Current distribution on the patch surface

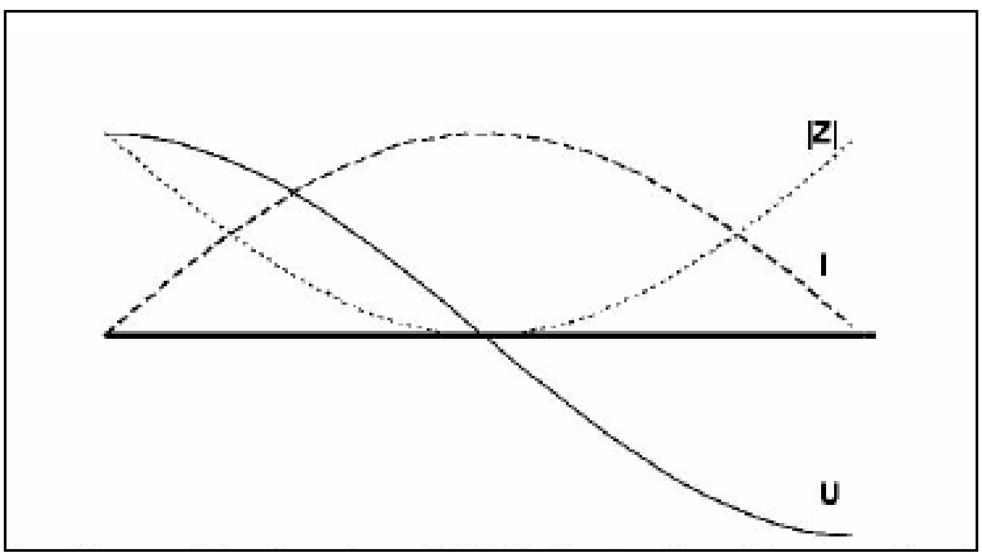


Figure 2.3: Voltage (U), Current (I), Impedance (Z) distribution along the patch's resonant length

From the magnitude of the current and the voltage, we can conclude the impedance is minimum (theoretically zero W) in the middle of the patch and maximum (typically around 200 W, but depending on the Q of the leaky cavity) near the edges. Put differently, there is a point where the impedance is 50 W somewhere along the "resonant length" (x) axis of the element.

2.3 Radiation Pattern

The patch's radiation at the fringing fields results in a certain farfield radiation pattern. This radiation pattern shows that the antenna radiates more power in a certain direction than another direction. The antenna is said to have certain directivity. This is commonly expressed in dB.

An estimation of the expected directivity of a patch can be derived with ease. The fringing fields at the radiating edges can be viewed as two radiating slots placed above a ground plane. Assuming all radiation occurs in one half of the hemisphere, this results in a 3 dB directivity. This case is often described as a perfect front to back ratio; all radiation towards the front and no radiation towards the back. This front to back ratio is highly dependent on ground plane size and shape in practical cases. Another 3 dB can be added since there are 2 slots. The slots are typically taken to have a length equal to the impedance width (length according to the y axis) of the patch and a width equal to the substrate height. Such a slot typically has a gain of about 2 to 3 dB .This results in a total gain of 8 to 9 dB.

The rectangular patch excited in its fundamental mode has a maximum directivity in the direction perpendicular to the patch (broadside). The directivity decreases when moving away from broadside towards lower elevations. The 3 dB beamwidth (or angular width) is twice the angle with respect to the angle of the maximum directivity, where this directivity has rolled off 3 dB with respect to the maximum directivity. An example of a radiation pattern can be found below.

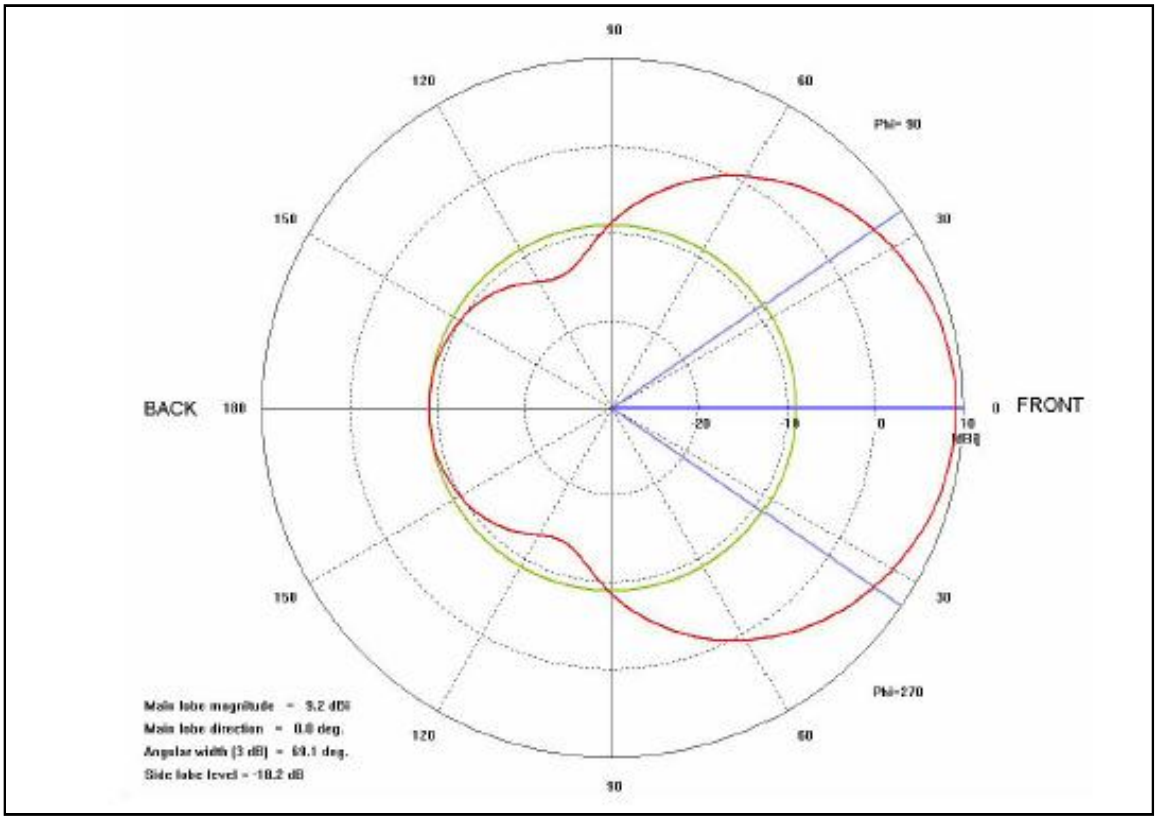


Figure 2.4: Typical radiation pattern of a square patch

So far, the directivity has been defined with respect to an isotropic source and hence has the unit dBi. An isotropic source radiates an equal amount of power in every direction. Quite often, the antenna directivity is specified with respect to the directivity of a dipole. The directivity of a dipole is 2.15 dBi with respect to an isotropic source. The directivity expressed with respect to the directivity of a dipole has dBd as its unit.

2.4 Antenna Gain

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

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

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

The gain of a rectangular microstrip patch antenna with air dielectric can be very roughly estimated as follows. Since the length of the patch, half a wavelength, is about the same as the length of a resonant dipole, we get about 2 dB of gain from the directivity relative to the vertical axis of the patch. If the patch is square, the pattern in the horizontal plane will be directional, somewhat as if the patch were a pair of dipoles separated by a half-wave; this counts for about another 2-3 dB. Finally, the addition of the ground plane cuts off most or all radiation behind the antenna, reducing the power averaged over all directions by a factor of 2 (and thus increasing the gain by 3 dB). Adding this all up, we get about 7-9 dB for a square patch, in good agreement with more sophisticated approaches.

2.5 Methods to Enhance Gain In Microstrip Patch Antenna

Most compact microstrip antenna designs show decreased antenna gain owing to the antenna size reduction. To overcome this disadvantage and obtain an enhanced antenna gain, several designs for gain-enhanced compact microstrip antennas with the loading of a high-permittivity dielectric superstrate or the inclusion of an amplifier-type active circuitry have been demonstrated.

Use of a high-permittivity superstrate loading technique gives an increase in antenna gain of about 10 dBi with a smaller radiating patch.

An amplifier-type active microstrip antenna as a transmitting antenna with enhanced gain and bandwidth has also been implemented.

2.6 Polarization

The plane wherein the electric field varies is also known as the polarization plane. The basic patch covered until now is linearly polarized since the electric field only varies in one direction. This polarization can be either vertical or horizontal depending on the orientation of the patch. A transmit antenna needs a receiving antenna with the same polarization for optimum operation. The patch mentioned yields horizontal polarization, as shown. When the antenna is rotated 90°, the current flows in the vertical plane, and is then vertically polarized.

A large number of applications, including satellite communication, have trouble with linear polarization because the orientation of the antennas is variable or unknown. Luckily, there is another kind of polarization circular polarization. In a circular polarized antenna, the electric field varies in two orthogonal planes (x and y direction) with the same magnitude and a 90°

phase difference. The result is the simultaneous excitation of two modes, i.e. the TM10 mode (mode in the x direction) and the TM01 (mode in the y direction). One of the modes is excited with a 90° phase delay with respect to the other mode. A circular polarized antenna can either be righthand circular polarized (RHCP) or lefthand circular polarized (LHCP). The antenna is RHCP when the phases are 0° and 90° for the antenna in the figure below when it radiates towards the reader, and it is LHCP when the phases are 0° and 90°.

2.7 Bandwidth

Another important parameter of any antenna is the bandwidth it covers. Only impedance bandwidth is specified most of the time. However, it is important to realize that several definitions of bandwidth exist impedance bandwidth, directivity bandwidth, polarization bandwidth, and efficiency bandwidth. Directivity and efficiency are often combined as gain bandwidth.

Impedance bandwidth/return loss bandwidth

This is the frequency range wherein the structure has a usable bandwidth compared to a certain impedance, usually 50 Ω. The impedance bandwidth depends on a large number of parameters related to the patch antenna element itself (e.g., quality factor) and the type of feed used. The plot below shows the return loss of a patch antenna and indicates the return loss bandwidth at the desired S11/VSWR (S11 wanted/VSWR wanted). The bandwidth is typically limited to a few percent. This is the major disadvantage of basic patch antennas.

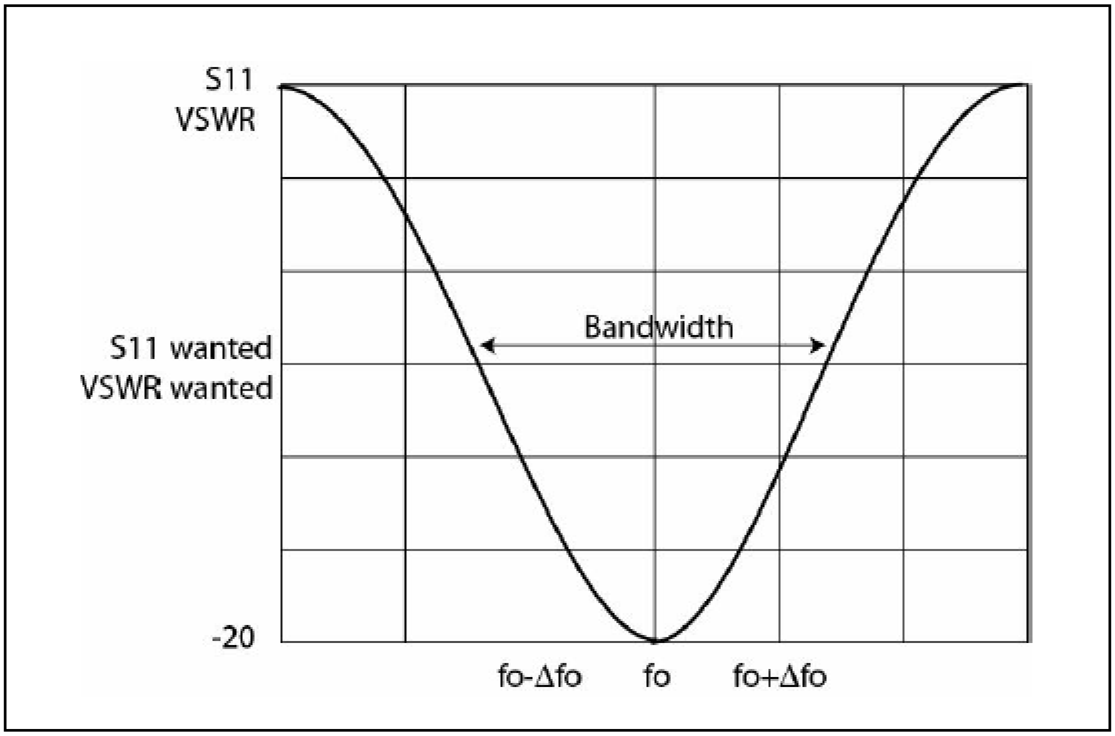


Figure 2.5: VSWR bandwidth Calculation

Important note: Different definitions of impedance bandwidth are used, such as:

VSWR = 2:1 and other values, S11 values other than –10 dB, the maximum real impedance divided by the square root of two [Z(Re)/√2, bandwidth], etc. This tends to turn selecting the right antenna for a specific application into quite a burden.

Directivity/gain bandwidth

This is the frequency range wherein the antenna meets a certain directivity/gain requirement (e.g., 1 dB gain flatness).

Efficiency bandwidth

This is the frequency range wherein the antenna has reasonable (application dependent) radiation/total efficiency.

Polarization bandwidth

This is the frequency range wherein the antenna maintains its polarization.

Axial ratio bandwidth

This bandwidth is related to the polarization bandwidth and this number expresses the quality of the circular polarization of an antenna.

CHAPTER 3

Study of U-slotted and E-shaped Microstrip Patch Antenna

3.1 Introduction

In this chapter, the design parameters and results for a U-slotted and E-shaped rectangular microstrip patch antenna in IE3D software is explained and the results obtained from the simulations are demonstrated. The microstrip patch design is achieved by using probe feed technique. These patches were studied because they offer high bandwidth and gain.

For conventional probe-fed microstrip antennas with a thick substrate, the major problem associated with impedance matching is the large probe reactance owing to the required long probe pin in the thick substrate layer. To solve this problem, a variety of designs with modified probe feeds have been reported. One design method is to cut an U slot in rectangular patch [3]. The radiating patch can be very high above the ground plane for this design and a long probe pin is not required. This behavior makes good impedance matching over a wide bandwidth.

3.2 Design Specifications for U-slotted rectangular patch

The essential parameters for the design of a rectangular microstrip Patch Antenna are:

•Length (L): The two sides are selected to be of equal length and is 36 mm each.

•Width (W): The two sides are selected to be of equal length and is 26 mm each.

•Frequency of operation (f_o): The resonant frequency of the antenna must be selected appropriately. The resonant frequency selected for our design is 4.5 GHz.

•Dielectric constant of the substrate (ε_r): The dielectric material selected for our design has a dielectric constant of 1.03. A substrate with a high dielectric constant has been selected since it reduces the dimensions of the antenna.

•Height of dielectric substrate (h): For the microstrip patch antenna to be used in cellular phones, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate is 5mm

•Slot Length along the X axis (l_x): The length of slot along the X axis was adjusted to be 12 mm in order to obtain better results.

•Slot Length along the Y axis (l_y): The length of both slots along the Y axis was adjusted to be 20 mm in order to obtain better results.

•Slot Width (w): The width of all the four slits was selected to be 2 mm.

Hence, the essential parameters for the design are:

• L = 36mm

• W = 26mm

• l_x = 12mm

• l_y = 20 mm

• w = 2mm

• f_o = 45 GHz

• ε_r = 1.03

• h = 5 mm

3.3 Simulation Results in IE3D for U-slotted patch

Designed Patch

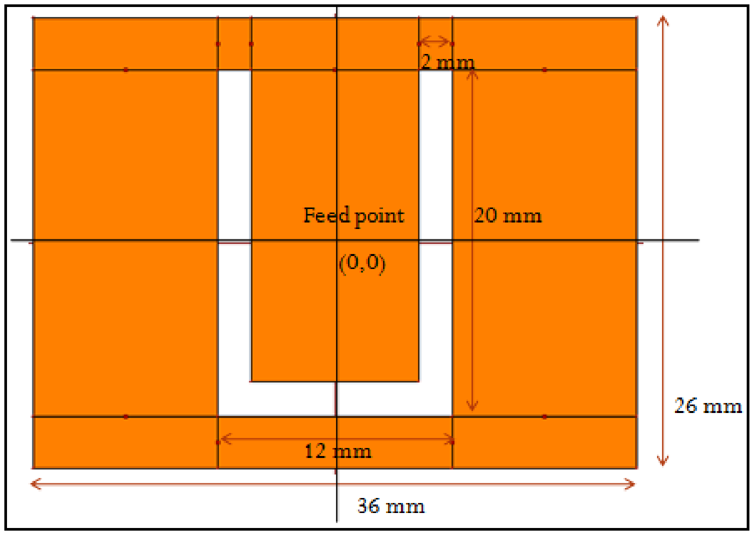


Figure 3.1: Designed Patch

S Parameter Display and Bandwidth calculation:

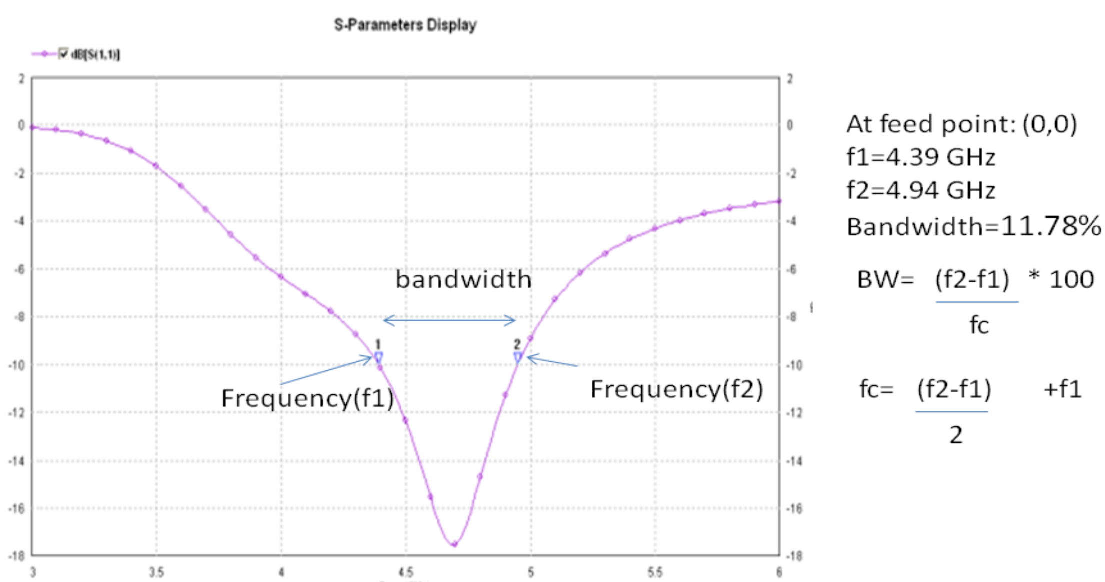


Figure 3.2: S Parameter display

The simulation is done by varying feeding positions and s-parameter is studied for each simulation and tabulated by taking each case. Thus the enhanced bandwidth of U-Slotted rectangular microstrip patch is obtained as 17.49% at probe feed position (0,-1).

3.4 Parametric Study of U-Slotted rectangular patch

Feed Point Position (mm,mm)	**FREQUEBCY(F1) (GHz)**	**FREQUENCY(F2) (GHz)**	**Bandwidth(%)**
(2,0)	**4.41**	**4.92**	**10.93%**
(-2,0)	**4.41**	**4.92**	**10.93%**
(0,-2)	**4.49**	**5.35**	**17.47%**
(0,-3)	**4.39**	**4.94**	**11.78%**
(0,-1)	**4.33**	**5.16**	**17.49% ***
(0,-0.5)	**4.34**	**5.06**	**15.31%**
(2,-2)	**4.51**	**5.31**	**16.29%**
(-2,-2)	**4.50**	**5.32**	**16.7%**

TABLE 3.1: S-parameter Study of U-Slotted rectangular patch by varying probe feed point position

As you can see in Table 3.1, there is no regular pattern of increment of bandwidth by varying feed position in one direction or the other. The s-parameter variation is studied at different feed positions in all directions all over the microstrip patch. The maximum bandwidth obtained in the above table is the enhanced bandwidth of the U-slotted microstrip patch antenna.

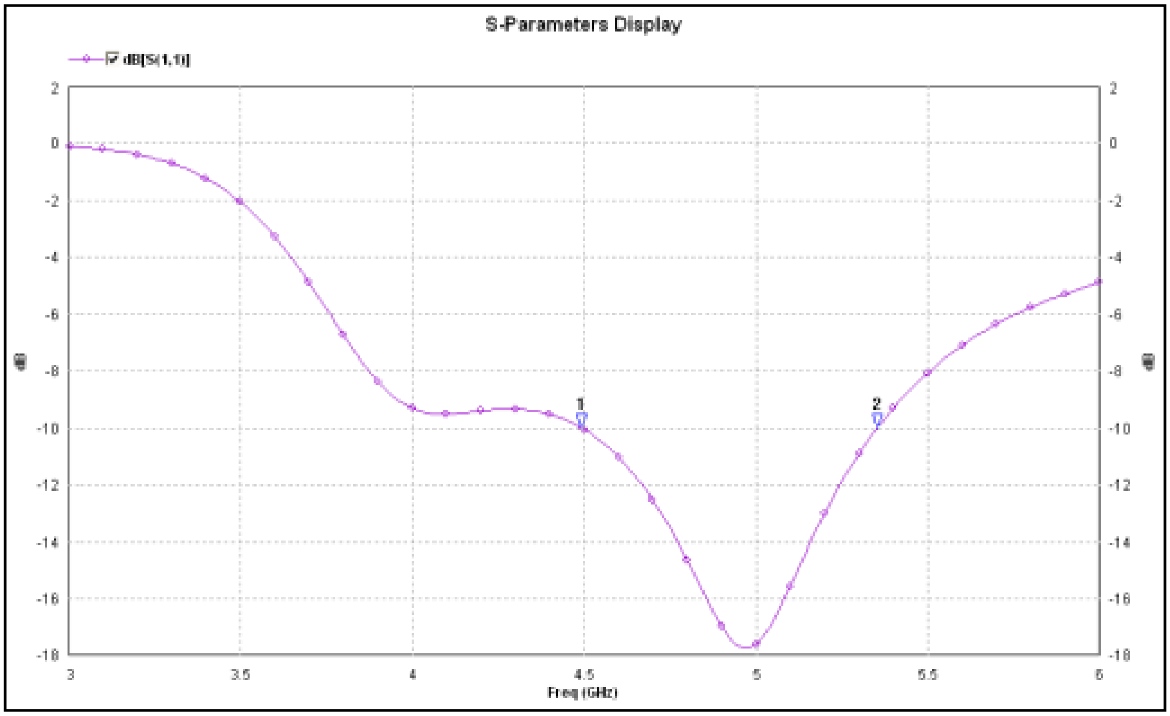


FIGURE 3.3: S-Parameter display with enhanced bandwidth

BANDWIDTH CALCULATION:

The bandwidth calculation at feed position (0,-1), we got maximum bandwidth. From the figure 3.3, frequency f_1 is taken as 4.33GHz and f_2 is taken as 5.16GHz. Therefore the bandwidth is obtained after doing calculation as shown in figure 3.1 as 17.49%.

3.5 Design of E-shaped patch with dual substrate

The E-shaped patch [2] [8] is formed by inserting a pair of wide slits at the boundary of a microstrip patch.

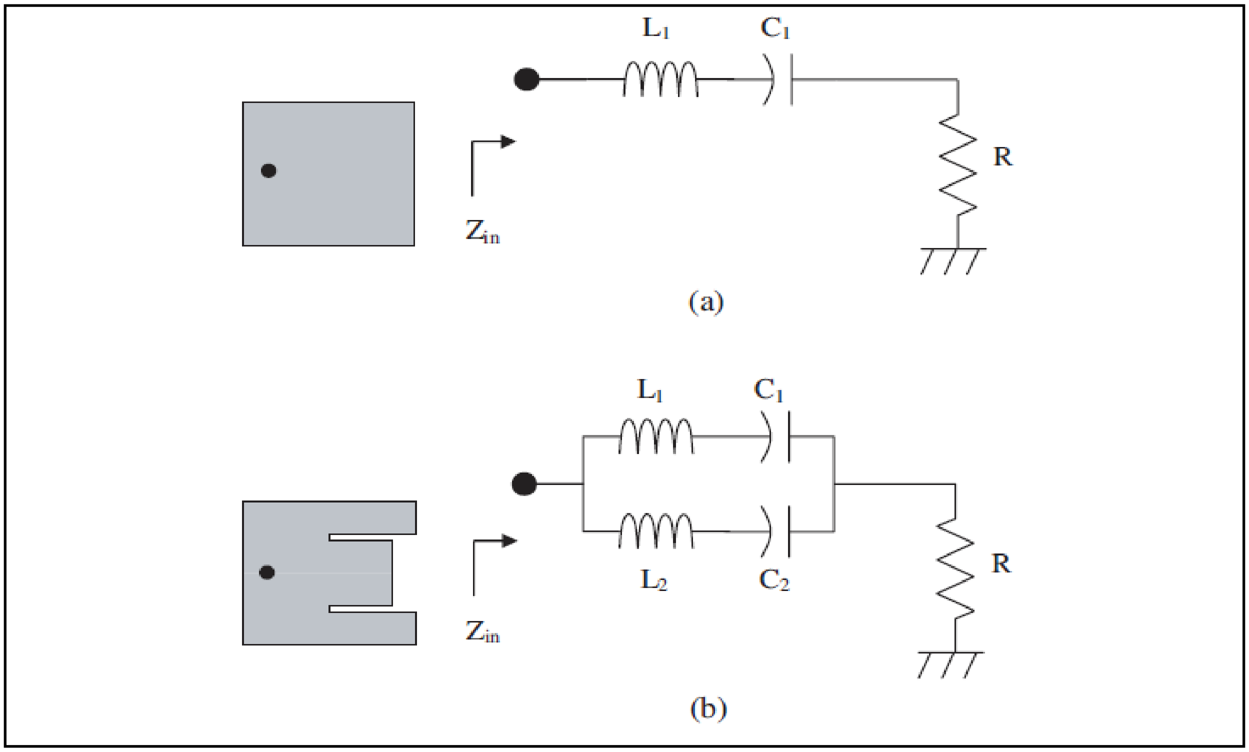


Figure 3.4: Equivalent circuits of (a) Rectangular Patch and (b) E-shaped Microstrip Antennas.

A common rectangular patch antenna can be represented by means of the equivalent circuit of Fig.(a). The resonant frequency is determined by $L1C1$. At the resonant frequency, the impedance of the series LC circuit is zero, and the antenna input impedance is given by resistance R. By varying the feed location, the value of resistance R may be controlled such that it matches the characteristic impedance of the coaxial feed. When a pair of slots is incorporated, the equivalent circuit can be modified into the form as shown in Fig.(b).

The second resonant frequency is determined by $L2C2$. Analysis of the circuit network shows that the antenna input impedance is given by

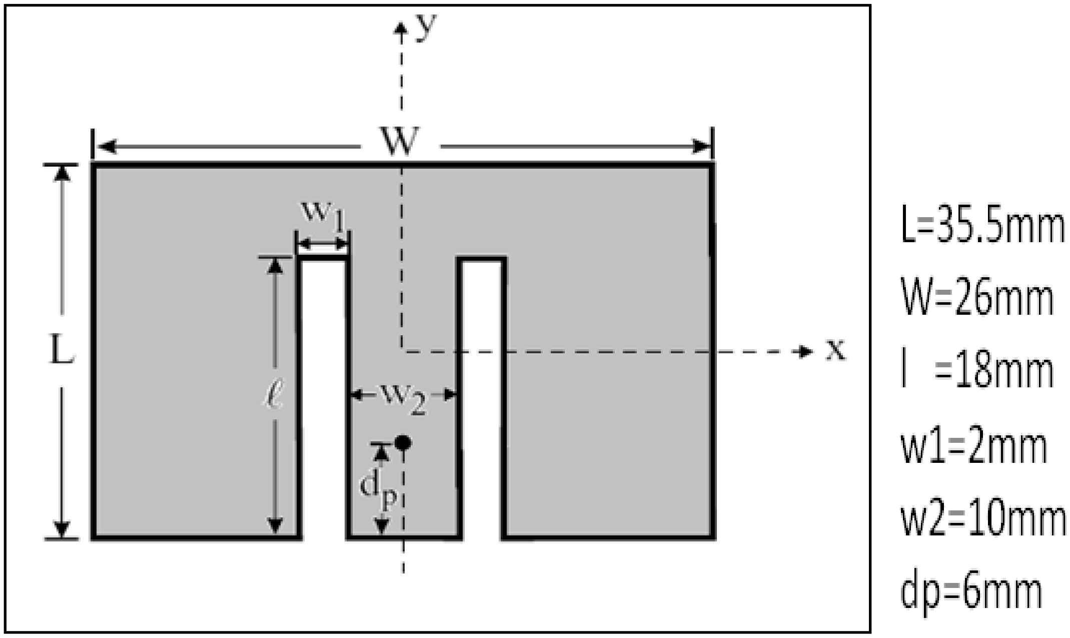
$$Z_{in} = R + j\frac{(\omega L_1 - 1/\omega C_1)(\omega L_2 - 1/\omega C_2)}{\omega (L_1 + L_2) - (1/\omega C_1 + 1/\omega C_2)}$$

The imaginary part of the input impedance is zero at the two series resonant frequencies determined by $L1C1$ and $L2C2$, respectively. Of course, this is by no mean the exact model of the E-shaped antenna because the equation shows that there is a parallel-resonant mode between the two series-resonant frequencies. Nevertheless, it serves to explain the operating principle of the antenna design. If the two series resonant frequencies are too far apart, the reactance of the antenna at the midband frequency may be too high and the reflection coefficient at the antenna input may be unsatisfactory. If the two series-resonant frequencies are set too near to each other, the parallel-resonant mode may affect the overall frequency response and the reflection coefficient near each of the series-resonant frequencies may be degraded. The question now is: how would the slot length, slot width, slot position and the length of center arm affect the values of $L2$ and $C2$ .This patch shape has shown to enhance gain as well as bandwidth of microstrip patch antenna.

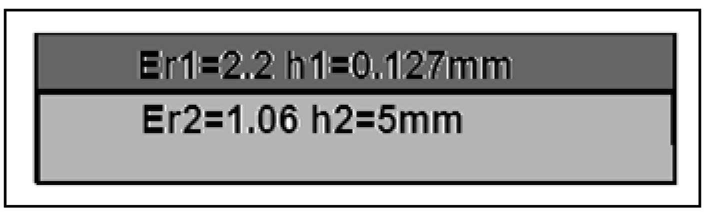
The need to use dual substrate

In order to further increase the bandwidth a foam material with very high thickness is used as a substrate. In order for the structure to be practically implementable it is placed below a substrate with 2.2 dielectric constant. The thickness of this substrate is very low to reduce dielectric losses.

3.6 E-shaped patch with coaxial probe feeding



(a)



(b)

Figure.3.5:(a) E-shaped patch (b) Substrate Dimensions

The geometry of the proposed antenna is shown in fig. (a). A rectangular patch of dimensions L x W separated from the ground plane using two substrates 1) a foam substrate (εr1) of thickness h1 and the other 2) substrate(εr2) of thickness h2. The E-shape is located in the center of the patch. The location of the slots on the patch can be specified by parameter W2. The width and length of the slots are denoted by W1 and l. The rectangular patch is fed using 50Ω coaxial probe with inner diameter of 0.65mm.

3.7 SIMULATED RESULTS AND DISCUSSION

In order to evaluate the performance of the proposed antenna, the antenna is simulated through the simulation tool IE3D^{TM}. The analysis of the antenna for different physical parameter values has been done by varying one of them and keeping others as constant. It is carried out here to study the flexibility in designing this of single layer patch antenna.

Parametric Study of E-patch by varying w1, w2 and l

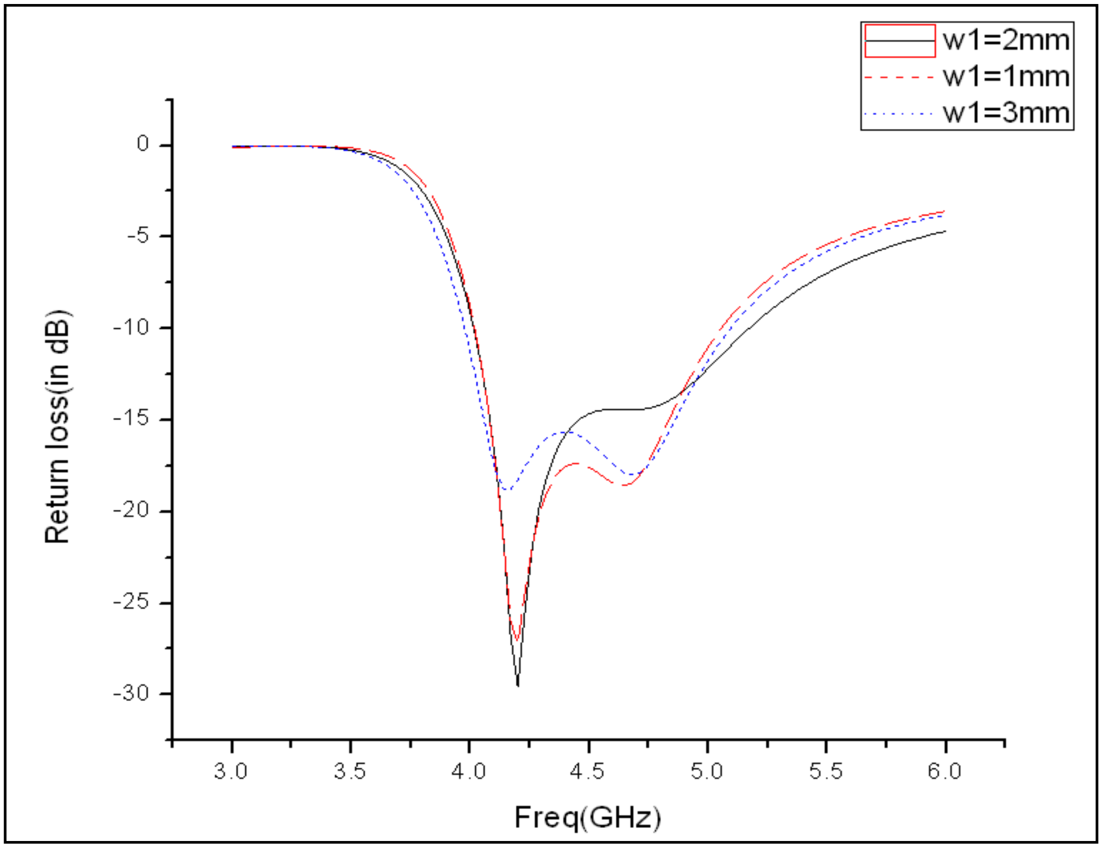


Figure 3.6: S-Parameter Results compared by varying slot width w1

From the figure 3.6, we find that the S-Parameter bandwidth is maximum for w1=2mm which is represented by continuous line. For other values of w1 the resonant frequency move closer towards each other reducing the overall bandwidth.

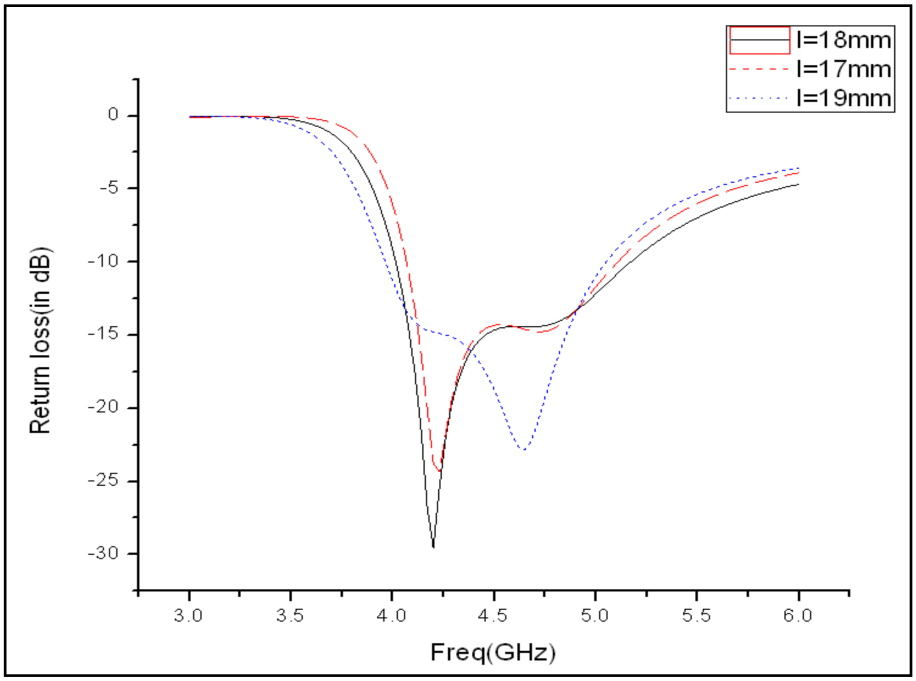


Figure 3.7: S-Parameter Results compared by varying slot length l

From the figure 3.7, we find that the S-Parameter bandwidth is maximum for l = 18mm which is represented by continuous line.

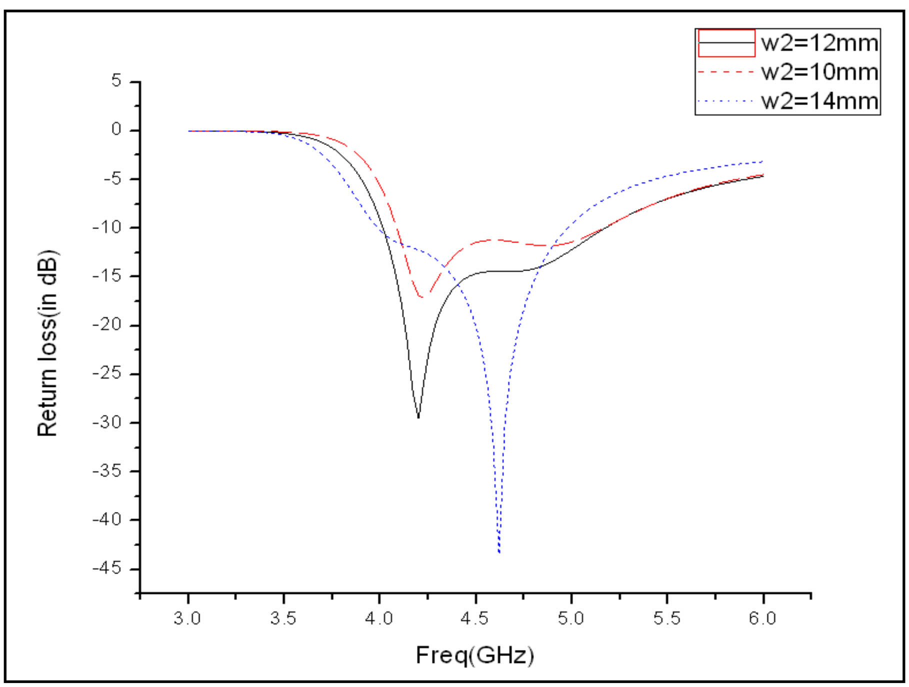


Figure 3.8: S-Parameter Results compared by varying slot width w2

From the figure 3.8, we find that the S-Parameter bandwidth is maximum for w2=12mm which is represented by continuous line. The S-Parameter is less than -10dB in the frequency range of 3.99 GHz to 5.17 GHz for the best result.

Best results were obtained for the following values of W1, W2, l and dp.

L =18mm

w1 =2mm

w2 =5mm

dp =6mm

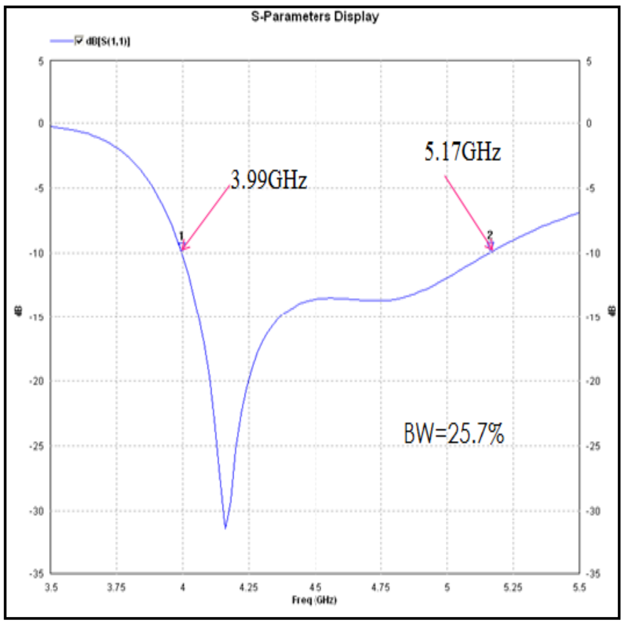


Figure 3.9: Simulated Return Loss curve

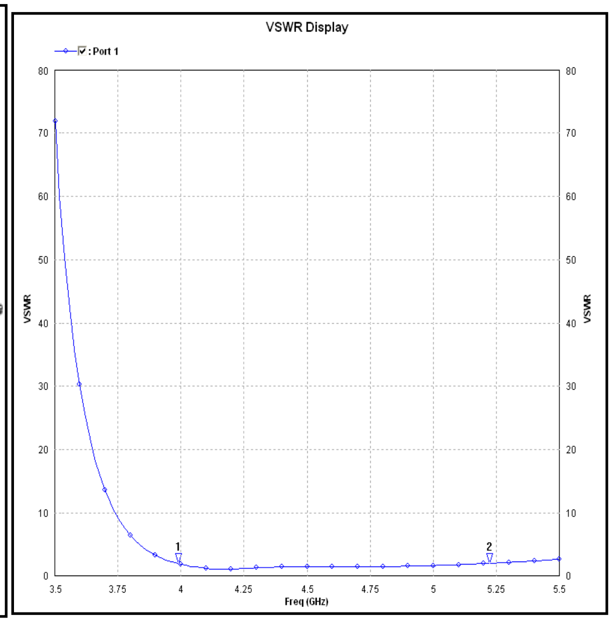


Figure 3.10: Simulated VSWR Curve

The simulated return loss value was found to be below -10dB within the frequency range of 3.99 GHz and 5.17 GHz. The value of VSWR was also found to be within 1 and 2 in this range. A bandwidth of 25.7% was achieved.

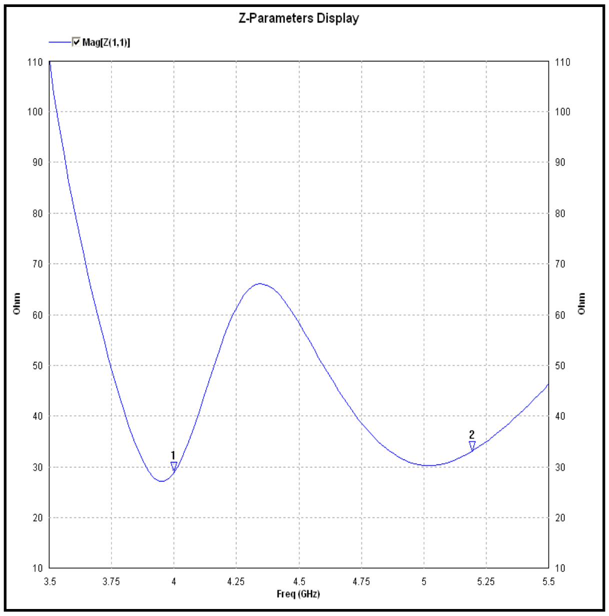


Figure 3.11: Simulated Z-parameter

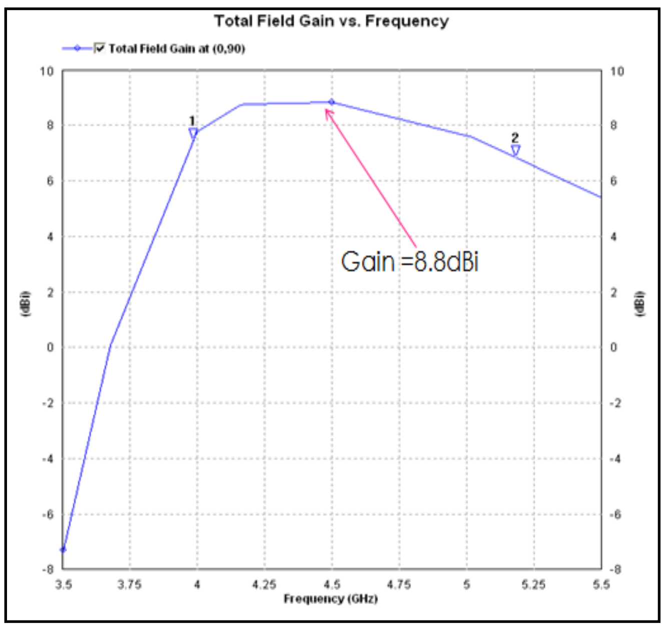
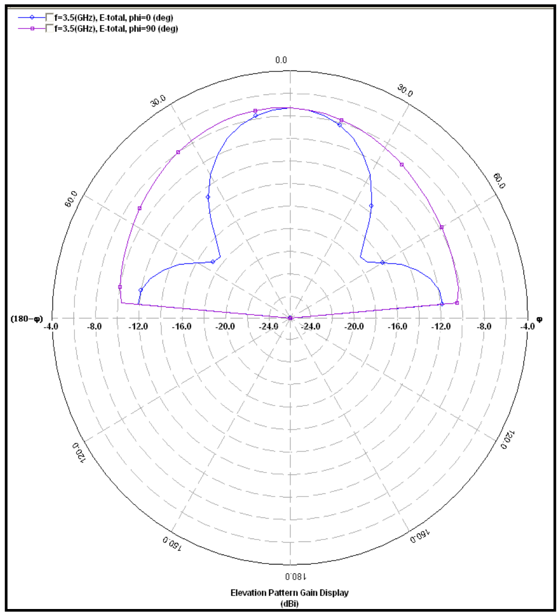
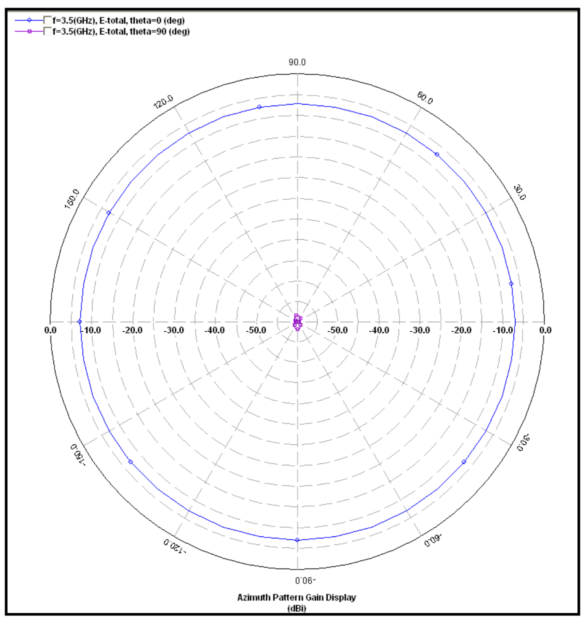


Figure 3.12: Gain Vs Frequency

A maximum gain 8.8 dBi was attained at the frequency of 4.50 GHz. The gain was found to be above 6 dBi in the entire bandwidth region. The Z-parameter was also within the acceptable range.



(a) E plane(x-z)



(b)H plane(y-z)

Figure 3.13: E and H plane Radiation Pattern

Good broadside radiation patterns are observed. However, relatively large cross-polarization radiation in the *H*-plane pattern is also seen, which is a common characteristic of this kind of probe-fed microstrip antenna with a thick air substrate.

Chapter 4

Design of Phi shaped Microstrip patch antenna in IE3D

4.1 INTRODUCTION

Both E shape and U slot loaded single layer rectangular microstrip patch antennas have shown the potential to give around 15-25% 2:1 VSWR impedance bandwidth on electrical thick substrate materials. In this chapter the phi-shaped [1] microstrip patch antenna with dual substrate is designed. It provides a much wider bandwidth than that of E-shaped patch [2].This increased bandwidth is attributed to improved control of the current distribution on the patch by the removal of bottom side conductors resulting in a tail part.

4.2 Design Specifications for phi-shaped rectangular patch

The essential parameters for the design of a rectangular microstrip Patch Antenna are:

•Length (L): The two sides are selected to be of equal length and is 48.5 mm each.

•Width (W): The two sides are selected to be of equal length and is 26 mm each.

•Dielectric constant of the substrates (ε_r): Two dielectric substrates were used to enhance bandwidth. The first one is foam substrate with dielectric constant 1.06 and height 6mm. The second substrate is microwave substrate with dielectric constant 2.2 and height 0.127mm.

•Slot Length along the X axis (Ws): The length of both slots along the X axis was adjusted to be 6 mm in order to obtain better results.

•Slot width along the Y axis (Ls): The width of both slots along the Y axis was adjusted to be 19 mm in order to obtain better results.

•Slot Width (w): The width of both the slots at the tail part was adjusted to be 6mm to obtain better results.

- Slot Width (l): The length of both the slots at the tail part was adjusted to be 23mm to obtain better results.

- Feed point position: The feed point position was adjusted to (0.6.7) to obtain better results.

Hence, the essential parameters for the design are:

- L = 48.5mm
- W = 26mm
- Ws = 6mm
- Ls = 19mm
- w = 6mm
- l=23mm
- ε_{r1} = 2.2, h1=0.127mm
- ε_{r2} = 1.06, h2=6mm
- Feed point position (0, 6.7)

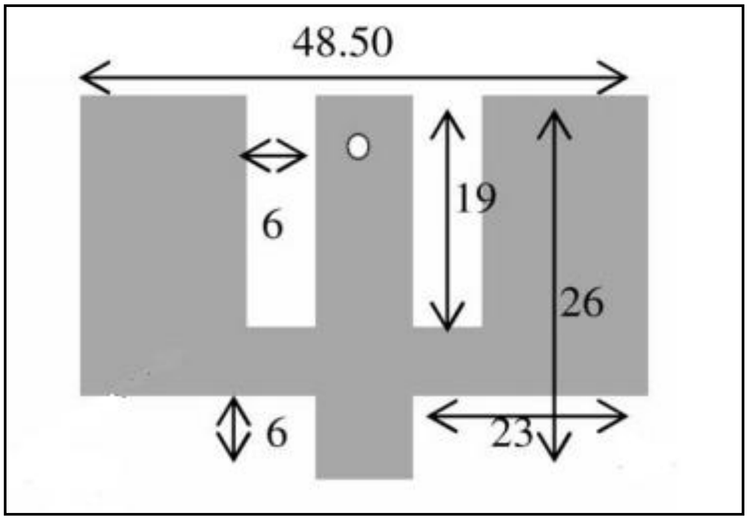


Figure 4.1: Phi shaped patch dimensions

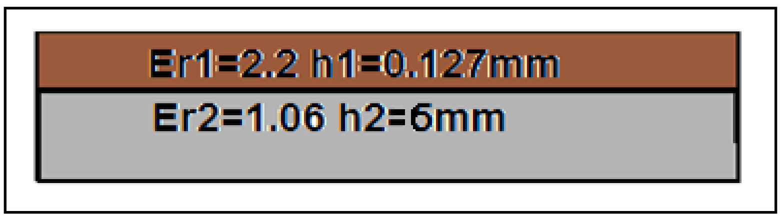


Figure 4.2: Phi shaped patch substrate specifications

4.3 SIMULATED RESULTS AND DISCUSSION

In order to evaluate the performance of the proposed antenna, the antenna is simulated through the simulation tool IE3D. The analysis of the antenna for different physical parameter values has been done by varying one of them and keeping others as constant. It is carried out here to study the flexibility in designing this of single layer patch antenna.

4.3.1 Enhancement of Bandwidth and gain by varying Ws, Ls, R and Feed position

By varying these width of the slot, length of the slot, radius of probe feed, and probe feed position the s-parameter variation is studied and bandwidth is enhanced for the phi-shaped microstrip patch.

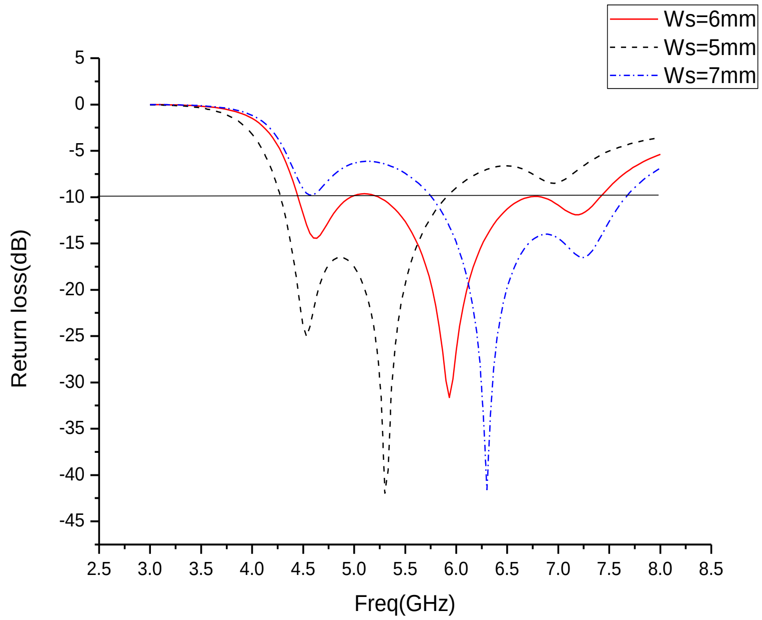


Figure 4.3: Comparing the results obtained by varying Width of the Slot(Ws).

As you can see in figure 4.3, increase in slot width increases the central resonant frequency and for Ws=6mm we got maximum bandwidth which is represented by continuous line.

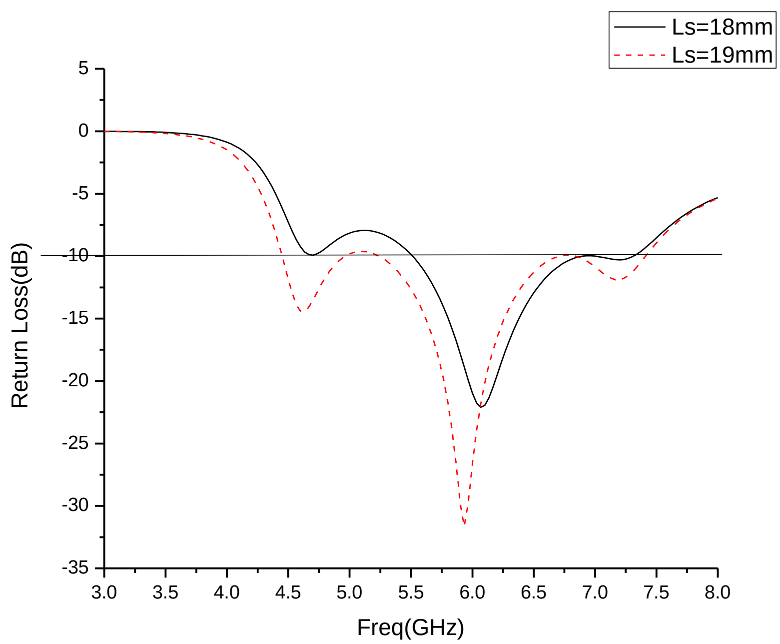


Figure 4.4: Comparing the results obtained by varying Length of the Slot(Ls).

As you can see in figure 4.4, the resonant frequency increases with increase in length of the slot but with increase in length of the slot the bandwidth is decreasing. For Ls=19mm we got maximum bandwidth which is represented by dotted line.

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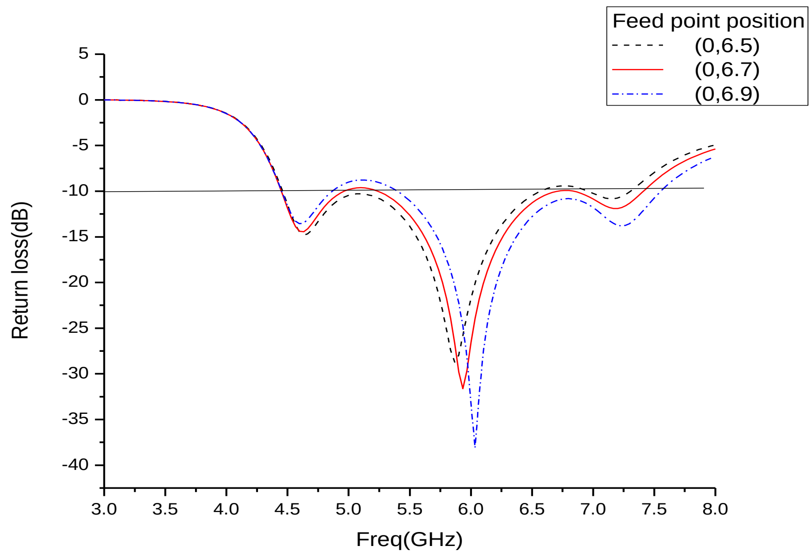


Figure 4.5: Comparing the results obtained by varying Feed point position

As you can see in figure 4.5, the bandwidth is maximum at probe feed position (0, 6.7) when compared to other feed positions which is represented by continuous line. The s-parameter variation is studied at different feed positions.

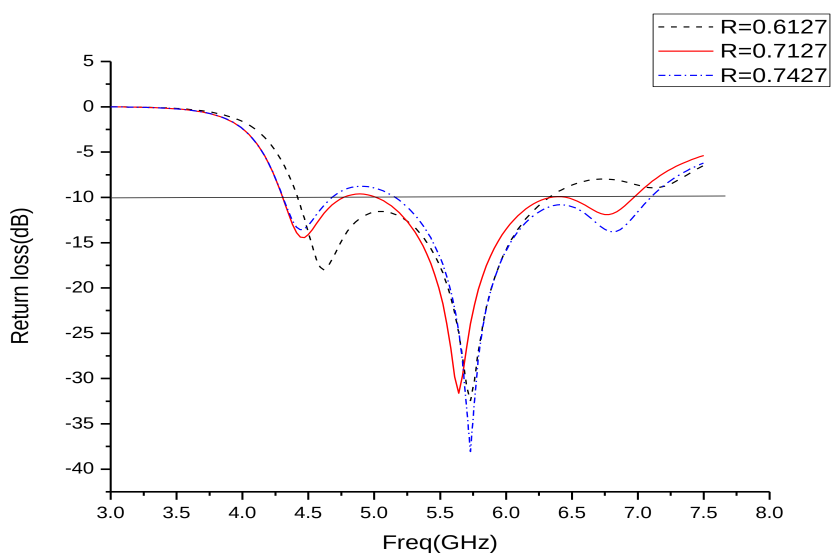


Figure 4.6: Comparing the results obtained by varying Radius of the Probe feed.

As you can see in figure 4.6, the resonant frequency is increasing with increase in radius of probe feed but bandwidth is decreasing. After studying variation of s-parameter by varying the radius of probe feed the maximum bandwidth is obtained when radius of probe feed as 0.7127mm which is represented by continuous line.

Best results were obtained for the following values of Ws, Ls, R and probe feed position.

Ls (length of the slot) = 19mm

Ws (width of the slot) = 6mm

R (radius of probe feed) = 0.7127mm

Probe feed position = (0, 6.7)

4.3.2 Return loss and VSWR display

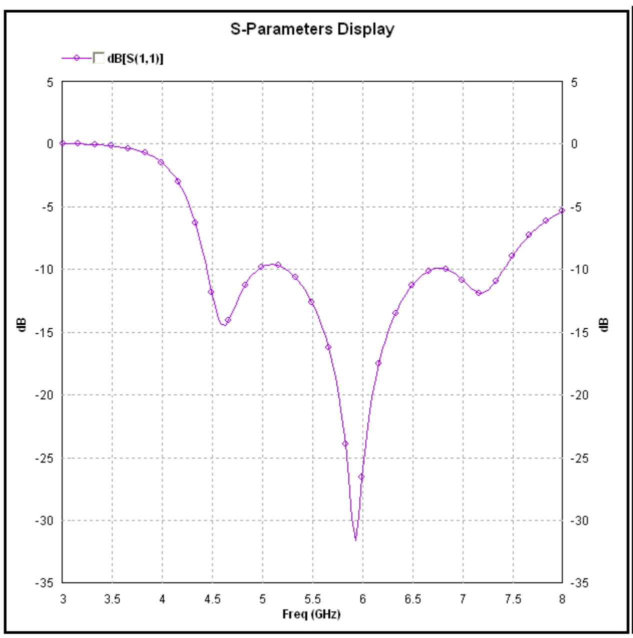


Figure 4.7: Simulated Return Loss curve

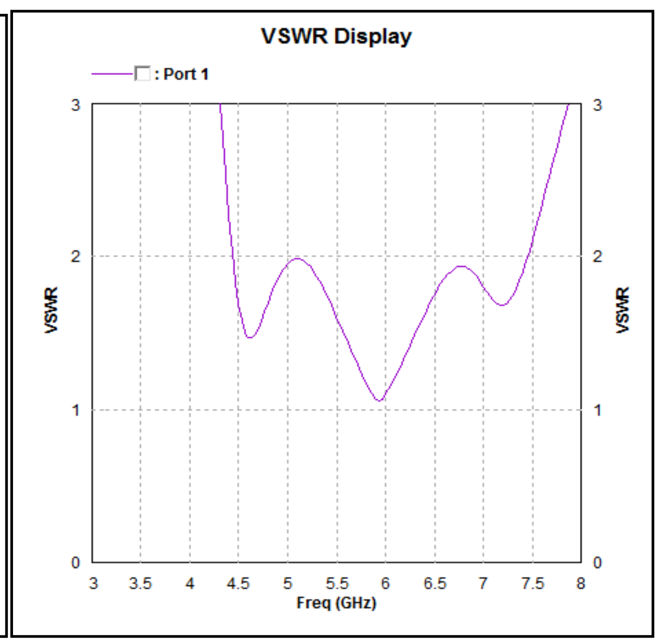


Figure 4.8: Simulated VSWR Curve

The simulated return loss is below −*10 dB from 4.45 GHz to 7.4 GHz except at 5.1GHz.* The antenna is thin and compact which makes it easily portable.

4.3.3 Z-Parameter Display and Antenna Gain

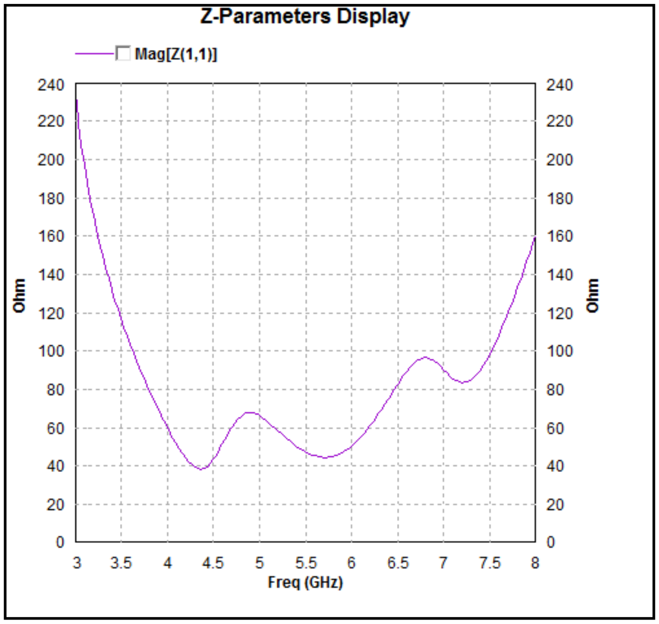


Figure 4.9: Simulated Z-parameter

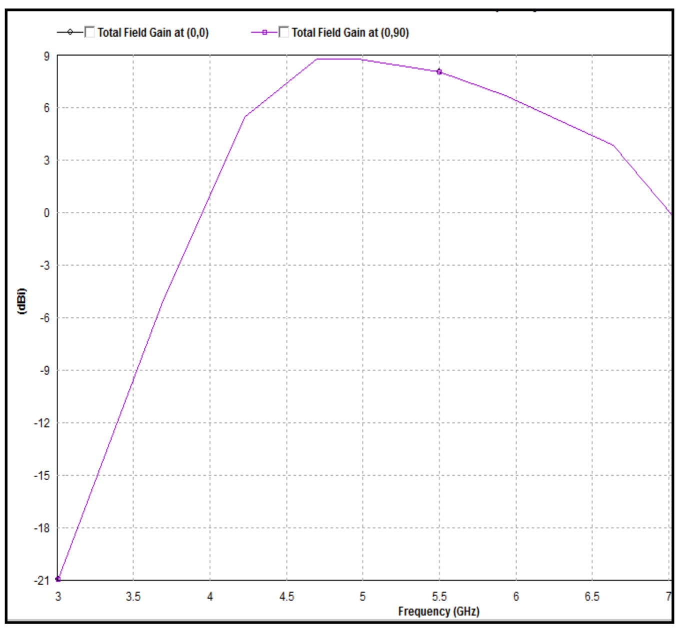
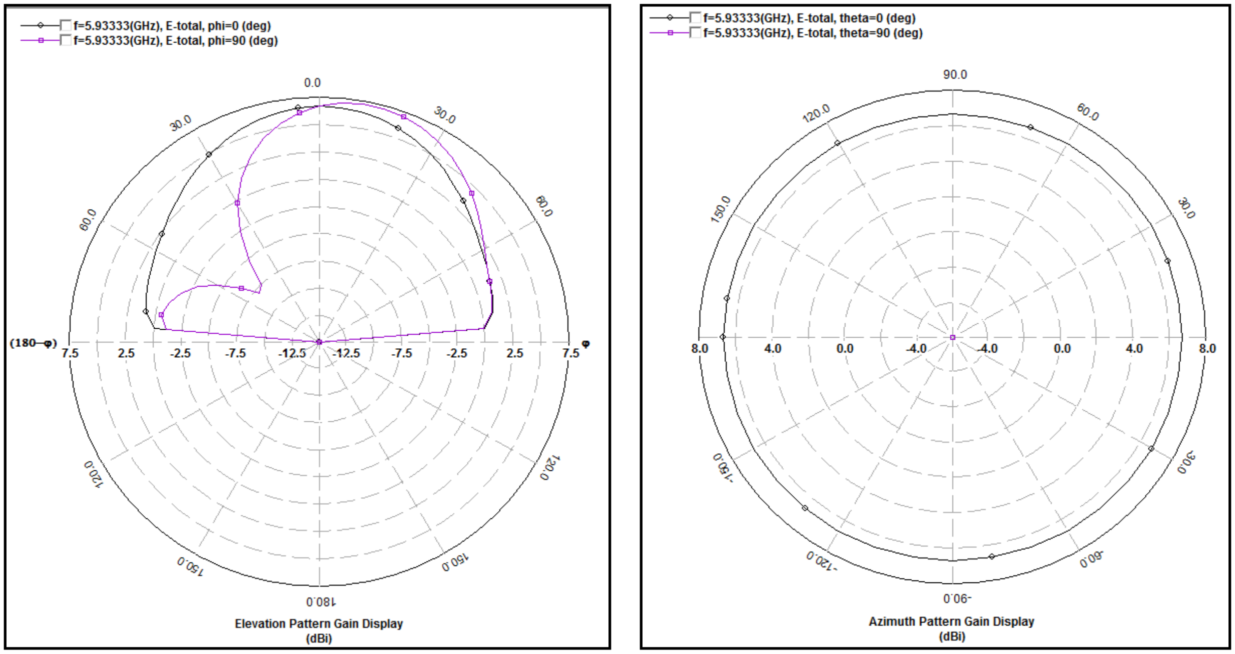


Figure 4.10: Gain Vs Frequency

A maximum gain of 8.77dB achieved at 4.7 GHz frequency. The Z-parameter was also within the acceptable range.

4.3.4 Radiation Pattern



E plane(x-z) H plane(y-z)

Figure 4.11: E and H plane Radiation Pattern

Good broadside radiation patterns are observed. However, relatively large cross-polarization radiation in the *H*-plane pattern is also seen, which is a common characteristic of this kind of probe-fed microstrip antenna with a thick air substrate. The drop in broad side gain at 6.5 GHz appears as a dip in the cross polarization patterns figure 4.10, which is due to the increase in cross polarization levels.

CHAPTER 5

CONCLUSION AND FUTURE PROSPECTS

We have designed three different wideband microstrip patch antennas. The characteristics of proposed antennas have been investigated through different parametric studies using IE3D simulation software. The proposed antennas have achieved good impedance matching, stable radiation patterns, and high gain. The phi-shaped antenna can be used for Wireless LAN application in the frequency range 5.2 to 5.8 GHz. Fabrication and Verification of simulated results can be carried out in future.

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