DESIGN AND ANALYSIS OF DUAL BAND MICROSTRIP PATCH ANTENNA

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IN

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CERTIFICATE

This is to certify that the thesis entitled**, "Design and analysis of dual band microstrip patch antenna"** submitted by Mr. **Sujeet Kumar Sethi** in partial fulfillment of the requirements for the award of **M.Tech Dual Degree** in Electronics and Communication Engineering with specialization in **"Communication and Signal Processing"** during session 2010-15 at the National Institute of Technology, Rourkela is an authentic work carried out by him 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.

Prof. S K Behera

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ABSTRACT

This thesis involves the design and analysis of Dual band Microstrip patch antenna which operates at lower and upper resonating frequency of 3.05 GHz and 7.24 GHz respectively. The antenna has been designed, modelled and simulated. Basically transmission line modelling approach has been used to model the antenna. The proposed antenna has been fed with 50Ω microstrip feed line. In the first frequency band we have bandwidth of 310MHz (2.91-3.22 GHz) with gain and directivity 3.304dB and 4.393dBi respectively. The second frequency band has a bandwidth of 580MHz (6.69-8.27 GHz) with gain and directivity of 3.534dB and 5.516dBi. Radiation efficiency at the two bands of operations are 75.12% and 63.52% respectively. Design parameters for the proposed antenna have been calculated from the transmission line model equations considering the effects of introducing inset notch parallel to the radiating edge of the antenna. Ground plane dimensions have been optimized by analyzing the antenna characteristics through parametric study. The CST Microwave Studio software has been used to implement the desired design and various antenna parameters have been studied. Furthermore, an attempt has been taken to calculate the return loss vs frequency response through MATLAB coding. The proposed antenna covers a good portion of S-band and C-band. It can be embedded in mobile devices for the purposes of mobile WiMAX, Wi-Fi, Bluetooth and WLAN operations due to its very small size and weight. Also it can be used by weather radar, surface ship radar, and some communications satellites for various surveillance and communication purposes.

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CHAPTER 1

THESIS OVERVIEW

1.1 Introduction

Antennas are very important components of communication systems. In the last few years, there has been a huge development in in the field of satellite and wireless communication where antenna is indispensable. Thus a lot of research has been going on in both government and commercial communication systems to develop low profile, inexpensive and minimal weight antennas which can be easily fabricated. These microstrip antennas can be so designed to radiate over a large range of frequencies and can be easily analysed with the available advanced design softwares. They are becoming very widespread within the mobile phone market.

One of the widespread use of an antenna is its dual band nature where the same antenna can be used to radiate in two different frequency bands. This thesis attempts to design and analyse dual band antennas and their prospects. Nowadays a lot of softwares have been developed for design and analysis of microstrip patch antennas out of which CST Microwave Studio has been used for the work mentioned in this thesis.

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 CST Microwave Studio, 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 to design dual band patch antennas and study their behaviour. Furthermore an attempt has been made to study the mathematical modelling through MATLAB simulations.

1.4 Thesis Outline

The outline of this thesis is as follows :

Chapter 1 :
It gives the overview of the thesis. Here a brief introduction is given about the growing need of antennas around the globe and how the proposed antenna qualifies to meet those needs. Also this chapter includes the thesis motivation, literature review and methodology.

Chapter 2 :
It presents the basic theory of microstrip antennas. It includes the basic geometries , feeding techniques and characteristics of the microstrip antennas. Also their advantages and disadvantages , impedance matching and shorting techniques are clearly explained. Then the methods of analysis used for the microstrip antenna design is given along with the calculations needed to find the dimensions of the conventional microstrip antennas. At the end a vivid study of microstrip antenna using transmission line model is presented.

Chapter 3 :

In this chapter the fundamentals of antenna parameters such as radiation pattern, gain , impedance, VSWR etc. are presented.

Chapter 4 :

In this chapter at first an introduction to dual frequency operation and dual band antenna has been presented. The various resonating modes existing inside the antenna is studied using basic electromagnetic theory and antenna design concepts. The geometry of the proposed design and its specifications have been clearly explained. Then various antenna characteristics such as return loss, gain, bandwidth, directivity etc. have been studied by using CST Microwave studio.

Chapter 5 :

This chapter contains conclusion and scope of future work. It clearly suggests the various ways of improving the proposed design to achieve better antenna performances by taking into consideration all sorts of scope to change the antenna geometry such as shorting the wall of antenna. It also explains how there has been a very less research in mathematical analysis of microstrip antenna, hence software such as MATLAB can be used to have a theoretical approach to study antenna parameters using mathematical modelling and can be compared with the results obtained from antenna design softwares such as CST Microwave studio.

CHAPTER 2

MICROSTRIP ANTENNA

2.1 Introduction to microstrip patch antenna

Microstrip antennas are low profile, low cost, conformable to planar and non-planar surfaces, simple to manufacture, mechanically robust and versatile in terms of resonant frequencies. Also using loads such as pins and varactor diodes between the patch and ground plane, a wide variety of adaptive elements with variable polarization, frequency, impedance and pattern can be designed.

These antennas find huge applications in missile applications, spacecraft, aircraft and satellite communications.

2.2 Basic characteristics

As shown in the Figure 2.1 the microstrip antenna is generally formed by etching a radiating patch made of conducting materials such as copper or gold and feeding lines on a dielectric substrate on the top and consists of a ground plane at the bottom which is a perfect reflector and bounces energy through the surface into the free space.

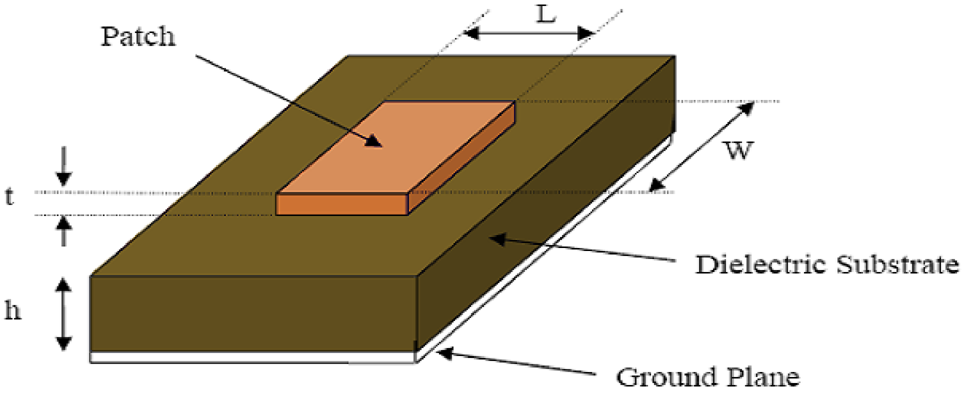


Figure 2.1 Structure of a Microstrip Patch Antenna

Though any geometry is possible for the design of patch antenna but generally rectangular and circular shapes find wide applications because of their simplicity and easy to do analysis.

There are various substrates which can be used for design of patch antennas with their dilectric constant usually in the range of $2.2 \leq \epsilon r \leq 12$. For rectangular patches length of the patch are generally in the range of $0.3333\lambda_0$ to $0.5\ \lambda_0$, where λ_0 is the wavelength in free space. Patch thickness is chosen very very less than λ_0.

2.3 Feeding methods

Many configurations are available for feeding microstrip antennas whereas the four most popular methods are the microstrip line, aperture coupling, coaxial probe feeding and proximity coupling.

2.3.1 Microstrip line feed

As shown in the Figure 2.2 this feeding technique involves connecting a conducting strip directly to the microstrip patch. The strip is smaller than the patch in terms of width and can be easily etched on the substrate to obtain a planar structure. In order to obtain good impedance matching an inset cut is incorporated into the patch thus there is no requirement of adding an extra matching element.

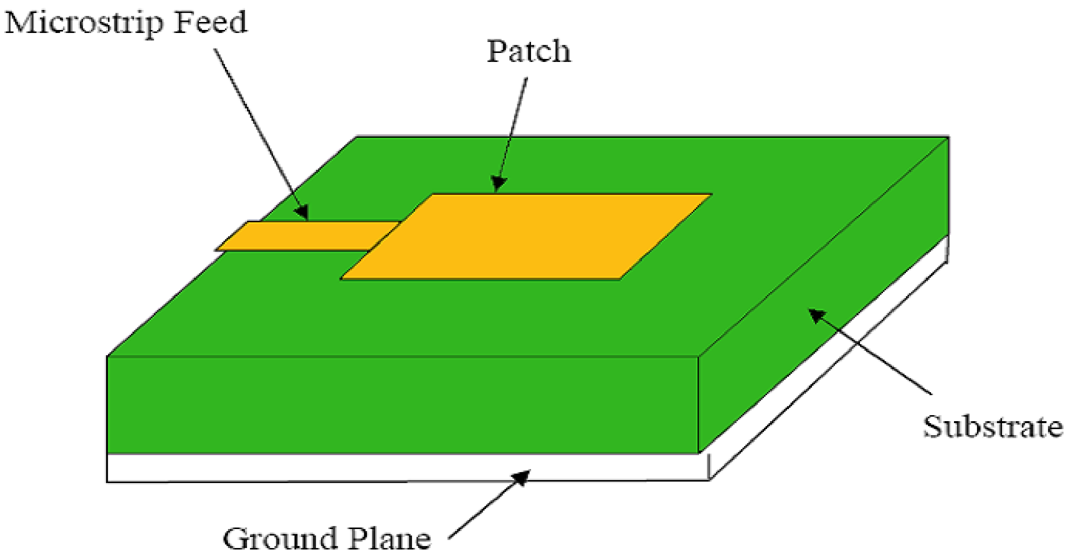


Figure 2.2 Microstrip line feeding

Thus this is an easy feeding technique, as it can be easily fabricated with simplicity in modelling and good impedance match.

However, with increase of substrate thickness there is increase in surface waves and spurious feed radiation also increase that hampers the bandwidth of the antenna. Further there are possiblities of undesirable cross polarization effects.

2.3.2 Coaxial Feed

Coaxial feed also known as probe feed is a very commonly used technique to feed microstrip patch antennas. This technque is appreciated for it has the advantage of placing the feed at any location inside the patch to get perfect impedance matching. The inner conductor of coaxial connector goes through the dielectric and is soldered to the radiating patch, whereas the outer conductor is connected to the ground plane which can be easily seen in Figure 2.3. Like microstrip feeding this technique is also easy to fabricate but has low spurious radiation. However it has a disadvantage of narrow bandwidth. Also the modelling is quite difficult especially when substrate thickness is high since a hole has to be drilled into the substrate. For thicker substrates input impedance becomes more inductive due to increase in probe length which leads to matching problems.

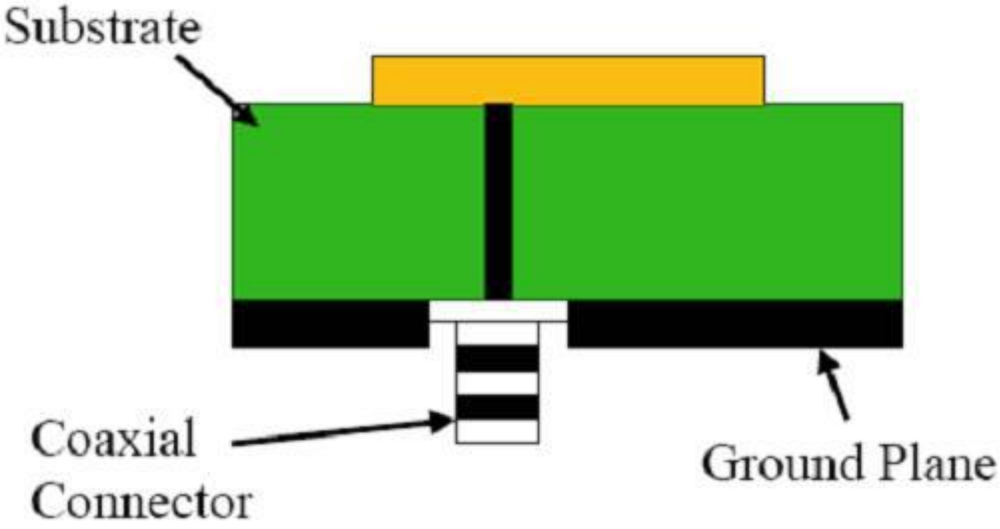


Figure 2.3 Coaxial feeding technique

2.3.3 Aperture Coupled Feed

In aperture coupled feed technique, the microstrip feed line and radiating patch are separated by the ground plane. As shown in Figure 2.4 we can see that the coupling between the patch and the feed line is done through a slot or an aperture in ground plane. The shape, size and location of the aperture determines the coupling amount from the feed line to patch. Here the spurious radiation is reduced since the patch is separated from feed line by ground plane.

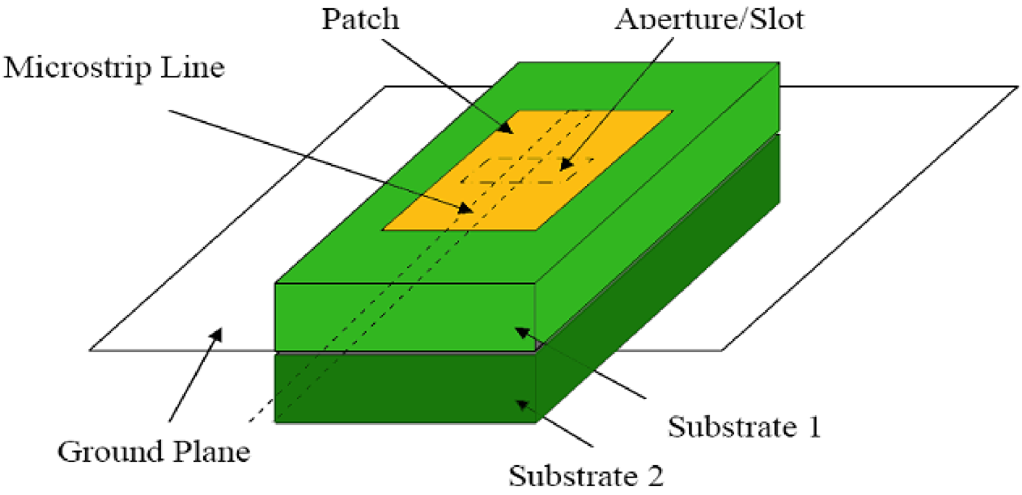


Figure 2.4 Aperture coupled feeding technique

Generally, the bottom substrate material is chosen to have a dielectric constant whereas a thick material with low dielectric constant is used for the top substrate so as to have optimized radiation from the patch. However, it is difficult to fabricate this technique due to multiple layers present. Also this technique provides narrow bandwidth.

2.3.4 Proximity coupled feed

This feeding technique is also known as the electromagnetic coupling scheme. As displayed in Figure 2.5, two substrates are used with feed line in between the substrates and top substrate containing the radiating patch. This technique eliminates spurious feed radiation and gives very high bandwith due to increase in the electrical thickness of the patch antenna. This technique also gives option to choose two different dielectric media for the patch and feed line to further optimize their individual performances. However the fabrication is bit complex which is a disadvantage.

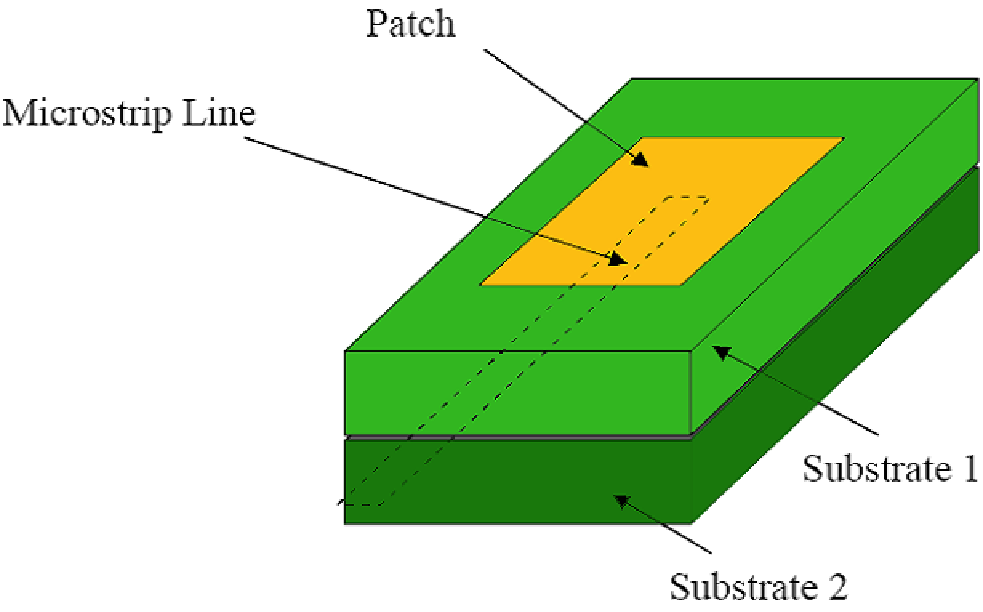


Figure 2.5 Microstrip antenna proximity coupled feed

2.4 Methods of analysis

The microstrip antenna can be analysed using different models like cavity model, transmission line model and full wave model. Out of these transmission line model is very simple for analysis but has less accuracy and becomes difficult to analyse coupling effect of antenna. On the other hand, cavity model has better accuracy but increased complexity especially while modelling coupling effect. Compared to these two models, full wave model gives great accuracy and is very versatile. It can be used to analyse single element, layered elements, finite array and other arbitrary shaped elements of microstrip antenna as well as their coupling effect.

2.4.1 Transmission line model

In this model the microstrip antenna is represented by two slots of width ‘W’ and height ‘h’ which are separated by a transmission line measuring length L. The microstrip is constituted by a non-homogenous line of two different dielectrics, typically the air and substrate. As can be seen in the Figure 2.6 the transmission line model of microstrip antenna shows the two slots separated by susceptance B and conductance G.

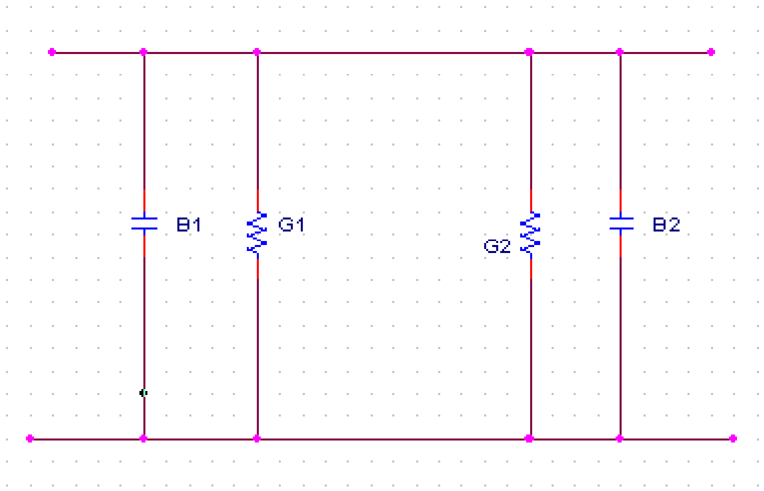


Figure 2.6 Transmission line representation

The insight of microstrip will state that though most of the electric field lines reside inside the substrate some of it exists in air too (as shown in Figure 2.7 (a)). As W/h >> 1 and dielectric constant being much greater than 1, most of the electric field lines exist inside the substrate. In this case fringing cause microstrip line look a little wider electrically as compared to its physical length (as shown in Figure 2.7 (b)). This in turn introduces an effective dielectric constant $\varepsilon reff$ inorder to account for the effect of fringing and wave propagation in the line. For a microstrip line with air above the substrate the effective dielectric constant ranges from 1 to εr whereas for most of the applications $\varepsilon reff$ is much closer to εr as dielectric constant is much greater than unity. The $\varepsilon reff$ is frequency dependent too. As microstrip antenna is operated with higher frequencies microstrip line behaves like a homogenous one of one dielectric and the effective dielectric gets closer in value to dielectric constant of the substrate.

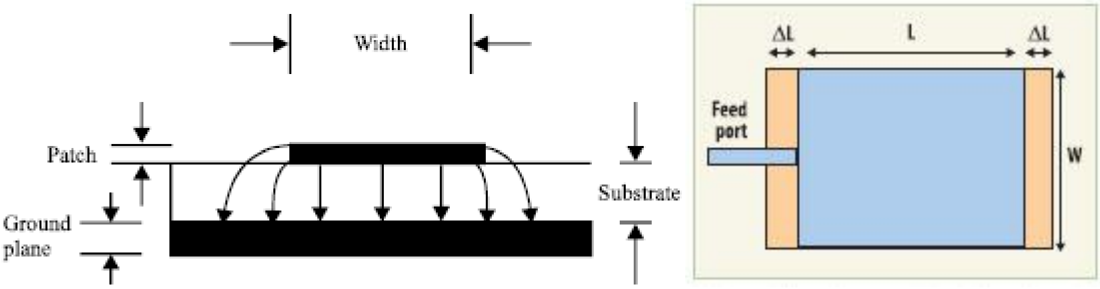


Figure 2.7 (a) Figure 2.7 (b)

Figure 2.7 Fringing effect in microstrip antenna

The $\varepsilon reff$ can be calculated as follows :

$$\varepsilon \text{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1 + 12\,\frac{h}{W}\right]^{-\frac{1}{2}}, \qquad (2\text{-}1)$$

where W = width of the patch

h = height of the substrate

$\varepsilon reff$= effective dielectric constant

εr= dielectric constant of substrate

The extension in length due to fringing effect is given by the expression :

$$\Delta L = 0.412h\frac{(\varepsilon_r + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)(\frac{W}{h} + 8)} \qquad (2\text{-}2)$$

Thus the effective length of the patch can be expressed as :

$L_{eff} = L + 2\Delta L$ (2-3)

In order to get maximum bandwidth, the substrate thickness should be sufficiently large keeping in mind the risk of surface wave excitation. Also, to get high efficiency dielectric constant of the substrate should be kept low. Now once we select the resonant frequency f_r , we can further determine the width W and length L of the patch given as :

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

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

(2-4(a) and 4(b))

Feeding the patch antenna at the end causes a high input impedance. This can be reduced by feeding the antenna closer to the centre as in inset feeding (Figure 2.8).

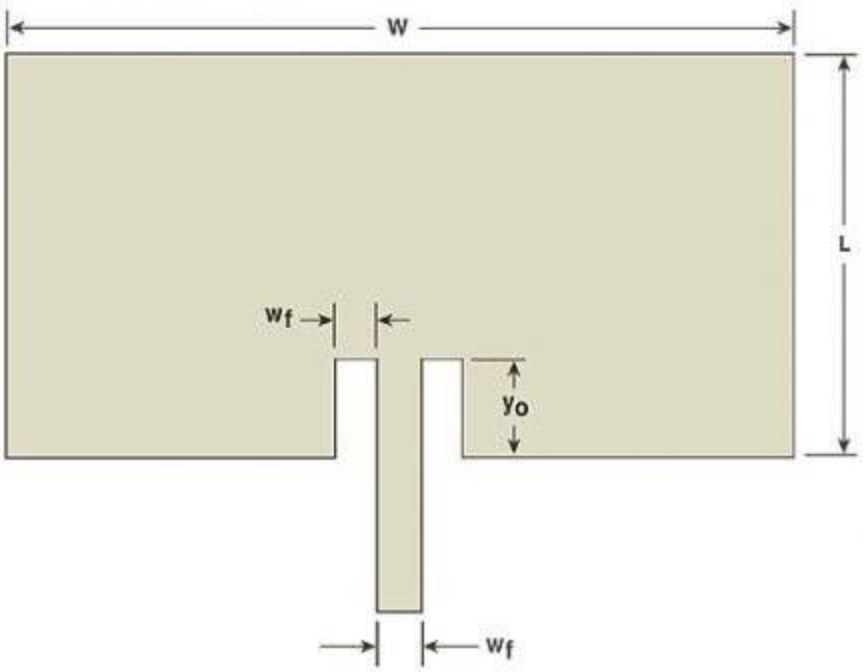


Figure 2.8 Microstrip patch antenna inset feed

As feed point is made to move in from the end the current increases whereas the voltage decreases by the same amount thus leading to decrease in input impedance.

2.4.2 Cavity model

Microstrip antennas are similar to dielectric-loaded cavities and exhibit higher order resonances. The normalized field between the patch and ground plane inside the dielectric substrate can be analysed more accurately by examining that region in the form of cavity bounded at top and bottom by electric conductors and magnetic walls running along the perimeter of the patch.

As soon as the microstrip antenna is energized, a charge distribution is developed on the upper and lower surfaces of the patch and ground plane (as shown in Figure 2.9).

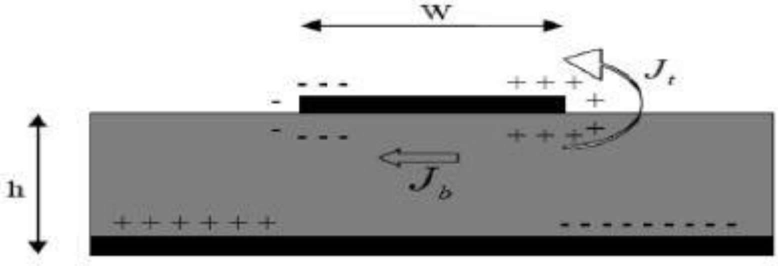


Figure 2.9 Charge distribution on microstrip patch

The charge distribution in the microstrip patch is judged by two mechanisms.

One is the attractive mechanism which exists between the corresponding opposite charges between the ground plane and the lower surface of the patch. Another is the repulsive mechanism which occurs between the like charges on the lower surface of patch, tending to push some charges existing at the lower suface around the edges to the upper side.

These charge movements create corresponding current densities at both top and bottom surfaces of the patch. Treating microstrip antenna only as a cavity is not sufficient to determine the absolute magnitudes of magnetic and electric fields. So the material inside the cavity and the cavity walls are treated as lossless so that the cavity will not radiate and will have purely reactive input impedance. The thickness of the microstrip antenna being usually very small, the waves generated within the substrate face considerable reflections as the field reaches the edge of the patch. Only TM field configuration is taken into account as the electric field is almost normal to the patch surface. The field configurations inside the cavity can be found using vector potential approach where the space beneath the patch is treated as a rectangular cavity loaded with a dielectric material which is assumed to be truncated within the edges of the patch.

The vector potential 'A' must obey the following homogenous wave equation :

$$\nabla^2 A_x + k^2 A_x = 0 \quad , \tag{2-5}$$

where

$$k^2 = \omega^2 \mu \varepsilon \tag{2-6}$$

The above wave equation has the solution expressed as :

$$A_x = [A_1 \cos(k_x x) + B_1 sink_x x][A_2 \cos(k_y y) + B_2 sink_y y][A_x \cos(k_z z) + B_x sink_z z] \tag{2-7}$$

where k_x, k_y and k_z are the wave-numbers along the respective x, y and z directions whose values are calculated according to the boundary conditions.

Relating the electric and magnetic fields to within the cavity to the vector potential A_x and applying the boundary conditions, the final form for the vector potential A_x is given as :

$$A_x = A_{mnp} \cos(k_x x')\cos(k_y y')\cos(k_z z') \quad , \tag{2-8}$$

where x', y', z' are the primed coordinates used to represent the fields within the cavity.

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

We need to examine the resonant frequencies in order to find the dominant mode with lowest resonance. Dominant mode is the one having the lowest order resonant frequency.

Arranging the resonant frequencies in ascending order determines the order of operational modes.

For all microstrip antennas with L and W very very greater than h :

1. If $h<W<L$, the mode related to the lowest frequency (i.e the dominant mode) is TM_{010} and its resonant frequency is given by :

$$(f_r)_{010} = \frac{1}{2L\sqrt{\mu\varepsilon}} \tag{2-9}$$

2. If L >W>L/2, the operating mode is TM_{001} and its resonant frequency is given by :

$$(f_r)_{001} = \frac{1}{2L\sqrt{\mu\varepsilon}} \tag{2-10}$$

3. If L>L/2>W>h, the order of the operating mode is TM_{020} and its resonant frequency is given by :

$$(f_r)_{020} = \frac{1}{2L\sqrt{\mu\varepsilon}} \tag{2-11}$$

If W>L>h, $TM^x{}_{001}$ becomes the dominant mode whose resonant frequency is given same as for TM_{001} while if W>W/2>L>h the 2nd order mode is $TM^x{}_{002}$.

The fringing effects and their influence should be taken into account while determining the resonant frequency.

CHAPTER 3

ANTENNA PARAMETERS

3.1 Gain and Directivity

The gain of antenna is expressed as the ratio of radiation intensity in a given direction to the radiation intensity of an isotropic antenna. An isotropic radiator is one which radiates equally in all directions. This antenna is taken as a reference while calculating the gain of any antenna. The most usual way of expressing gain is in decibels (dB). The gain with respect to isotropic radiator is expressed in terms of dBi and with reference to half-wave dipole is expressed in dBd.

Directivity is expressed as the ratio of radiation intensity in a particular direction from the antenna to the average of radiation intensity taken in all directions. The average radiation intensity is total power radiated by antenna divided by 4π.

3.2 Antenna polarization

It is defined as the orientation of electric field vector at a point in space. The polarization can be linear, circular or elliptical. If the orientation remains same at a point with respect to time it is said to be linear polarization, if it rotates as the wave passes through that point then it is either circular or linear polarization.

3.3 Input impedance

There are three kinds of impedance related to antennas. They are : terminal impedance, characteristic impedance and wave impedance. Terminal impedance is expressed as the ratio of voltage to current at the antenna connections. Characteristic impedance is one the important parameters of a transmission line. The closer the characteristic impedance to the terminal impedance of the antenna the better is the coupling. When the characteristic impedance is equal to the terminal impedance, the antenna is said to be perfectly matched to the line.

3.4 Voltage Standing Wave Ratio

Voltage standing wave ratio determines how efficiently the antenna is coupled to the transmission line. It is the ratio of maximum to minimum voltage along the transmission line. Since the ratio is greater to smaller, VSWR is always greater than equal to 1. Specifically when there is no reflection it is equal to 1. 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 terminal impedance of the antenna exhibits no reactive part and the resistive part is equal to the characteristic impedance of the line, then the antenna and the transmission line are said to be matched. It states that any of the RF signal sent to the antenna will not be reflected at its terminals. There are no standing waves on the transmission line and the VSWR is one. But, if the transmission line and the antenna are not matched, then some part of the RF signal sent to the antenna is being reflected back along the transmission line. This causes standing wave, characterized by minima and maxima, to exist on the line. Hence, the VSWR is having a value greater than one. The VSWR can be easily measured with a device. VSWR equal to 1.5 is considered excellent, while values ranging from 1.5 to 2.0 is considered good, whereas values greater than 2.0 may be unacceptable.

3.5 Bandwidth

The bandwidth of an antenna is expressed as the frequency range within which the antenna performs. So all the antenna characteristics (like gain, radiation pattern, terminal impedance etc) have considerably acceptable values within the bandwidth limits. In case of most of the antennas, gain and radiation pattern do not change rapidly with frequency as compared to the terminal impedance. As the characteristic impedance of the transmission line hardly changes with frequency, VSWR is a very useful and practical way to describe the terminal impedance effects and to specify antenna’s bandwidth. The bandwidth for broadband antennas, is usually expressed as the ratio of upper to lower frequencies in the region of acceptable operation. However, the bandwidth for narrowband antennas, is expressed in percentage of the bandwidth.

3.6 Quality factor

The quality factor relates to the various antenna losses which can be conduction, radiation, dielectric and surface wave losses. The relation between these quality factors are related as follows :

$$\frac{1}{Q_t} = \frac{1}{Q_{rad}} + \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_{sc}} \tag{3-1}$$

Where, Q_t = Total quality 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

CHAPTER 4

DUAL BAND MICROSTRIP ANTENNA

4.1 Dual Band concept

The boom in wireless communication technology sector has led to increased demand for highly efficient antennas with high bandwidth and maximum gain. Microstrip patch antennas have the advantage over other antennas being very light weight and economical. They exhibit very low profile and can be realized very easily. However, the general microstrip patch antennas have some disadvantages such as narrow bandwidth etc. Their performance need to be enhanced so as to achieve greater bandwidth.

There are a huge number of methods available to enhance the bandwidth of microstrip antennas, such as increasing the substrate thickness, using low dielectric constant for substrate, slotted patch antenna, incorporating various techniques for impedance matching and feeding methods. 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} 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 TM_{30} modes cannot be used owing to the facts that the TM_{20} pattern has a broad side null and the pattern has grating lobes. The easiest method to simultaneously operate at two frequencies is to consider the first resonance of the existing two orthogonal dimensions of the rectangular patch antenna, which are the TM_{10} and TM_{01} modes. Here the frequency ratio is given by the ratio of two orthogonal sides which is an approximate value. Though this approach is very much acceptable in terms of simplicity but has an disadvantage that two orthogonal polarizations are excited because of the two different frequencies. However, when much stress is not given to the polarization this method can be used without a hitch such as in short range low cost applications.

The most widely used techniques to design a dual-band antenna incorporates reactive loading by introducing stubs[3], notches [7], pins [5] , capacitors [6], and slots [9-12] to the microstrip patch. By using different reactive loading various resonating modes can be obtained and they can be modified so as to have good matching of radiation pattern characteristics between the fundamental mode and the higher mode.

Though adjustable coaxial stub can be used as reactive loading for tuning and design of frequency ratio but it does not suit well for high frequencies. So another way is to introduce a spur line or inset parallel to the radiating edge of the patch antenna which can significantly reduce the size of the antenna. However, frequency ratio greater than 1.2 cannot be designed without including pattern distortion or strong cross-polarization levels at the additional frequency.

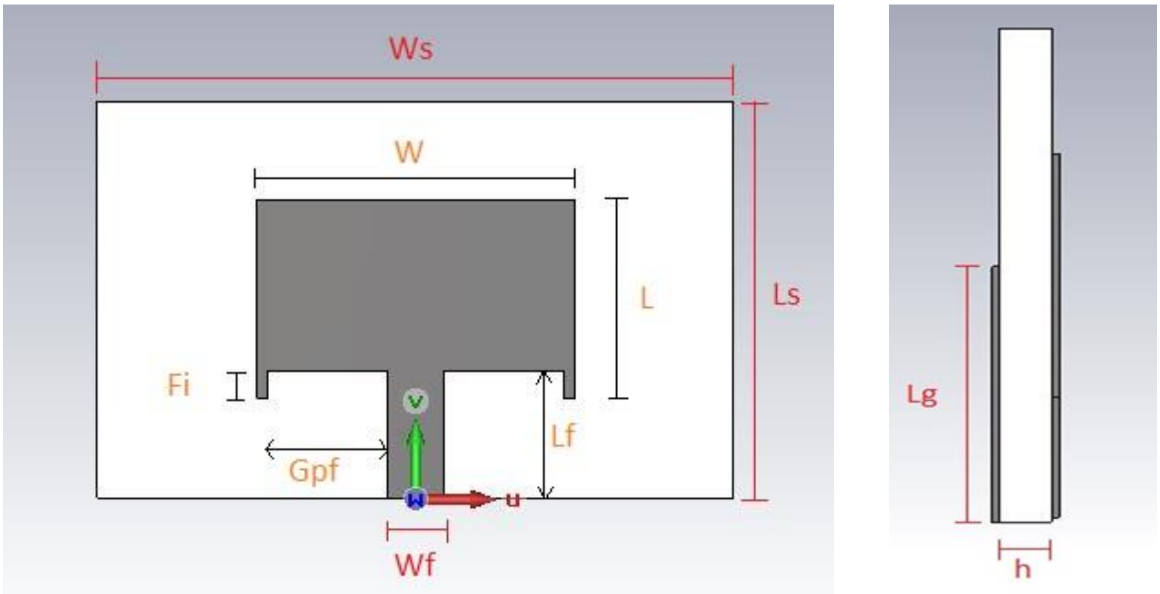
Different approaches can be considered for achieving higher values of the frequency raio. Like lumped capacitors or shorting vias can be used in between the ground plane and the patch so as to modify TM_{100} and TM_{300} modes . As presented in [16], by placing the shorting pin where the minimum current distribution exists for TM_{300} mode a strong disturbance occurs at the resonating frequency, while the TM_{100} mode is undisturbed. This allows the scope of increasing the number of vias to increase frequency ratio from 2 to 2.
However it has the disadvantage of undesired radiation pattern at TM_{300} mode due to spurious lobes.
Pin diodes can be used to change the loading behaviour to have better frequency agility. Two lumped capacitors can be connected between the ground plane and patch to obtain high frequency ratios.

Another way of incorporating reactive loading is by etching slots on the patch. With the introduction of slot loading the current lines of unperturbed mode are hindered which gives room for strong modification of the resonant modes. Frequency ratio can be increased from 1.3 to 3 by simultaneous introduction of short circuit vias and slots.

Other ways of slot-loaded patches may include the etching of two narrow slots which are close and parallel to the radiating edge.

4.2 Design specifications of proposed dual band antenna

4.2.1 Proposed design



Front view

Side view

Figure 4.1 Geometry of dual band antenna

This design consists of microstrip patch made of copper of 0.7mm thickness etched over a 4.56mm thick FR 4 lossy substrate with dielectric constant 4.3. The bottom side of the substrate is etched with a 0.7mm thick copper material which constitutes the ground plane.

The patch antenna has been introduced with two inset notches one on each side of the microstrip feed line. The introduction of notch creates an additional current distribution thus introducing an additional $TM_{0\delta}$ resonant mode along with the previously existing resonant mode of the patch antenna while unchanging the same polarization.

4.2.2 Design parameters

The following table lists the dimensions of the proposed design :

Width of the Patch	45 mm
Effective dielectric constant of the Patch	4.3
Length of the Patch	28 mm
Width of Microstrip line	8 mm
Width of inset notch	17 mm
Length of inset notch	4 mm
Width of ground plane	90 mm
Length of ground plane	29 mm
Patch thickness	0.7 mm
Height of the substrate	4.56 mm

The dimensions of patch, ground plane, feed line width, inset notch etc. have important effects on the impedance matching and thus the resonant frequencies of the antenna. Varying these dimensions thus helps to analyse the antenna characteristics over the range of frequencies.

4.3 Simulations and Results

4.3.1 S parameter characteristics

The S-parameter plot shows the variation of return loss (in dB) over a range of frequencies. Since at resonance the antenna is having the best impedance matching so the return loss would be minimum. The centre frequency of the antenna can be seen as 3.05 GHz and after the introduction of inset notch we are having another resonance at 7.24 GHz (as shown in Figure 4.2 (a) and (b)).

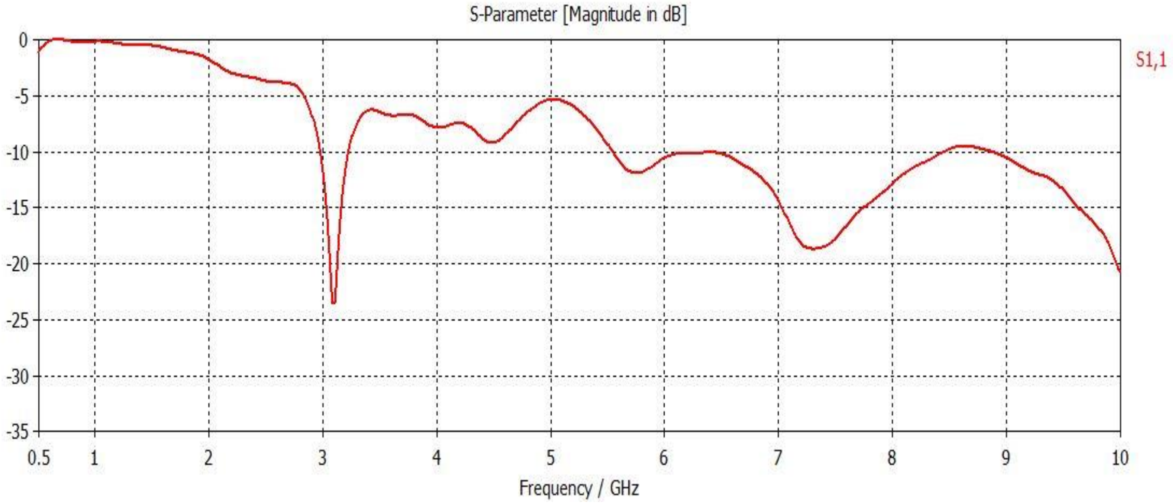


Figure 4.2(a) S parameter plot before the introduction of notch

The return loss characteristics as shown in Figure 4.2 (a) is the one obtained by simulating the microstrip patch antenna through CST Microwave studio software.

The antenna is designed at the central frequency of 3.05GHz using the basic transmission line modelling equations. Hence a return loss of -23dB is obtained at 3.05GHz as seen in the above figure.

A MATLAB code has been designed to compare the simulated antenna return loss characteristic with theoretical approach.

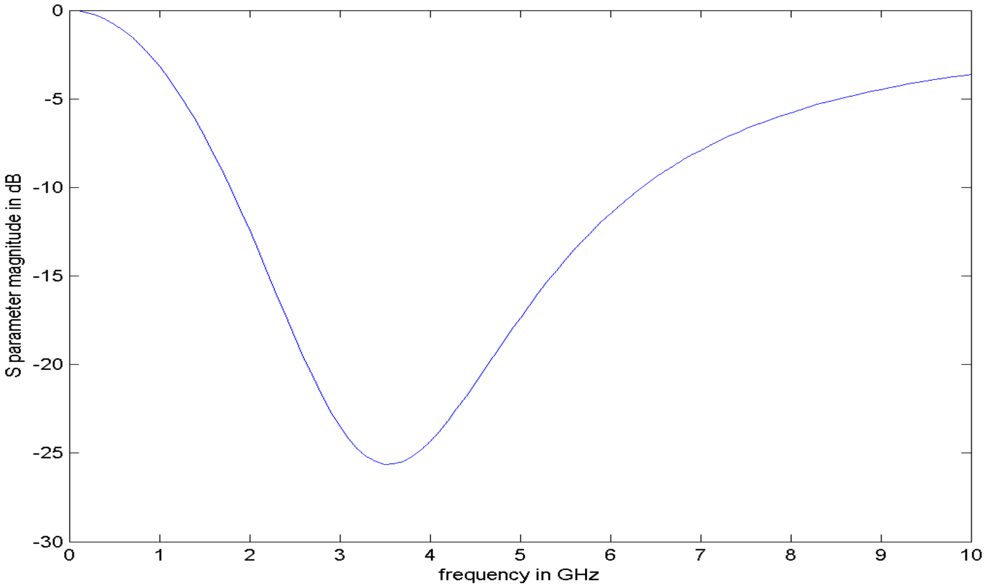


Figure 4.2(b) Matlab simulation

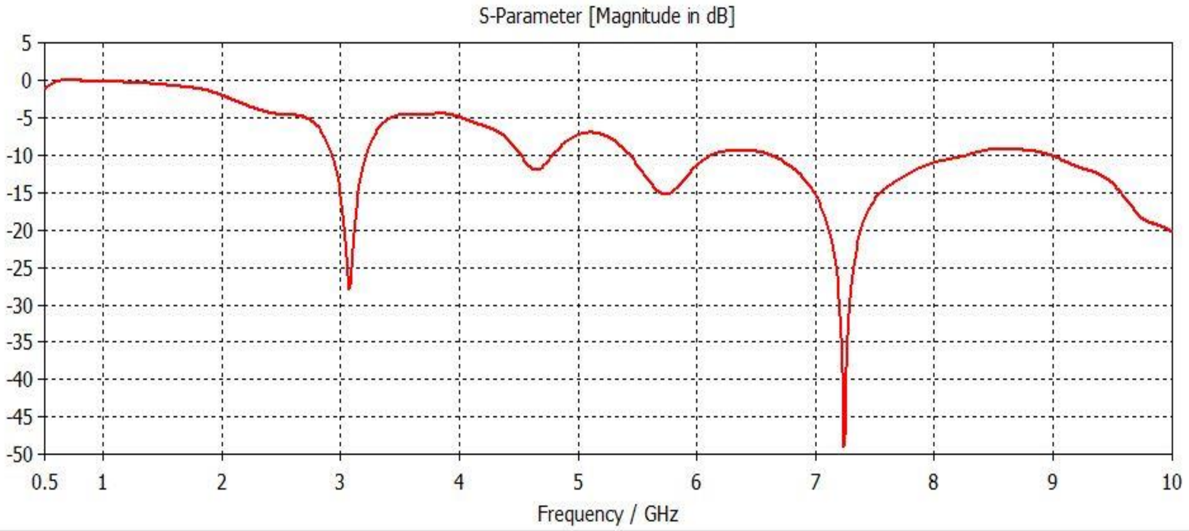


Figure 4.2(c) S parameter plot after the introduction of notch

The upper resonant frequency decreases while the lower resonant frequency decreases with increase in inset depth at constant inset width(Figure 4.3 (a)). Thus frequency ratio decreases with increase in inset depth.

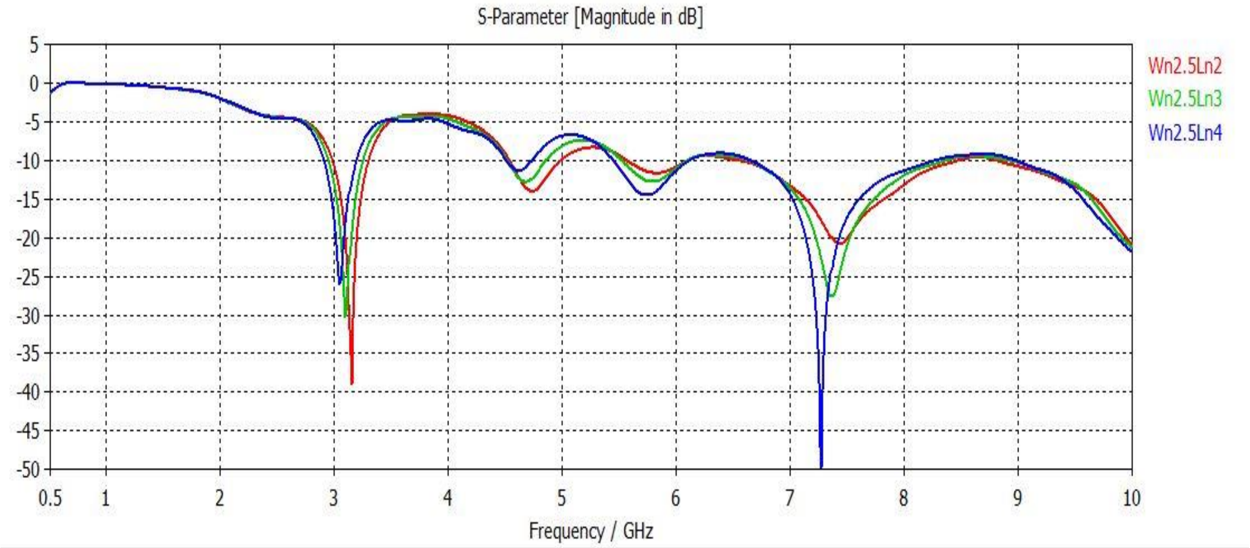


Figure 4.3 (a) S parameter plot for varying inset notch depth (Ln = 2mm, 3mm, 4mm)

Also from Figure 4.3 (b) it can be seen that variation of inset width has no impact on the lower resonant frequency whereas the upper resonant frequency increases while having subsequent increase in return loss. Hence the frequency ratio increases with increase in inset width.

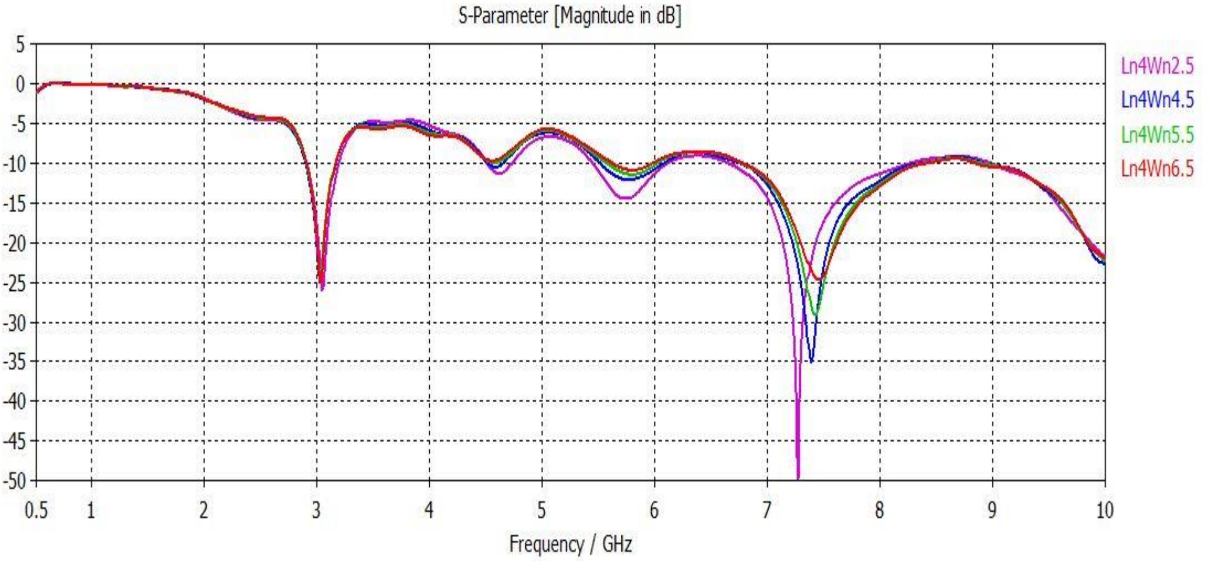
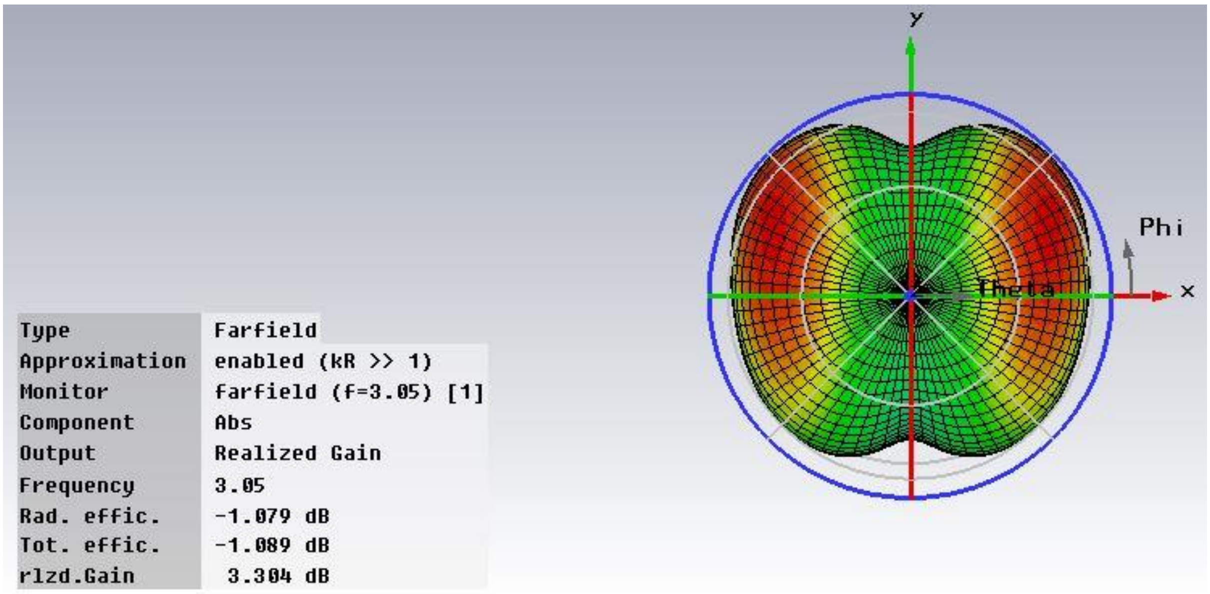


Figure 4.3 (b) S parameter plot for varying inset width (Wn = 2.5, 4.5, 5.5, 6.5)

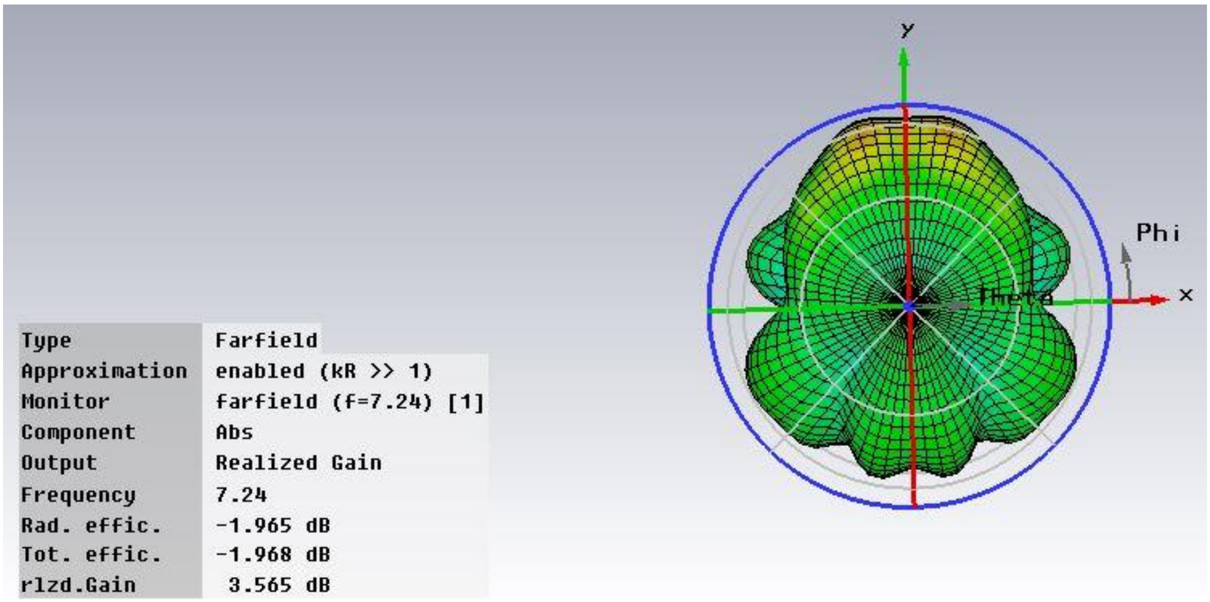
4.3.2 Radiation pattern plot

3D farfield radiation plot



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=3.05) [1]
Component	Abs
Output	Realized Gain
Frequency	3.05
Rad. effic.	-1.079 dB
Tot. effic.	-1.089 dB
rlzd.Gain	3.304 dB

Figure 4.4 (a) Realized gain at F_r = 3.05 GHz



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=7.24) [1]
Component	Abs
Output	Realized Gain
Frequency	7.24
Rad. effic.	-1.965 dB
Tot. effic.	-1.968 dB
rlzd.Gain	3.565 dB

Figure 4.4 (b) Realized gain plot at F_r = 7.24 GHz

It can be seen that the antenna is having a realized gain of 3.565 dB at 7.24 GHz and 3.304 dB at 3.05 GHz.

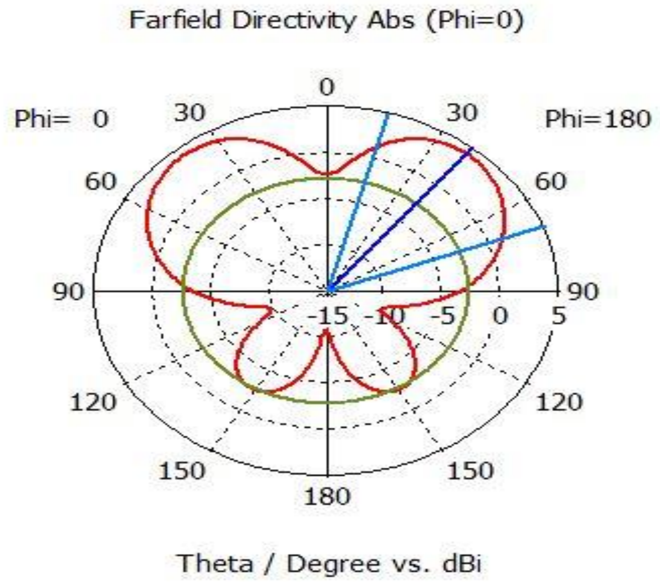


Figure 4.5 (a) Farfield Directivity at phi = 0 for $f_r = 3.05$ GHz

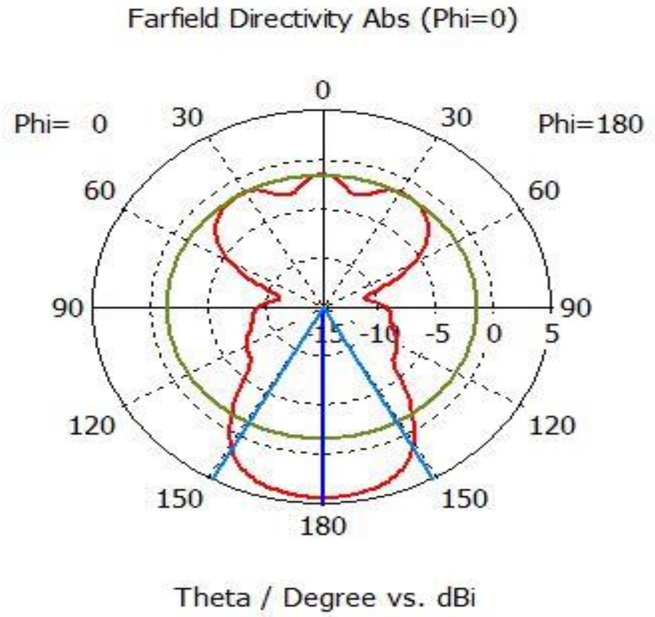
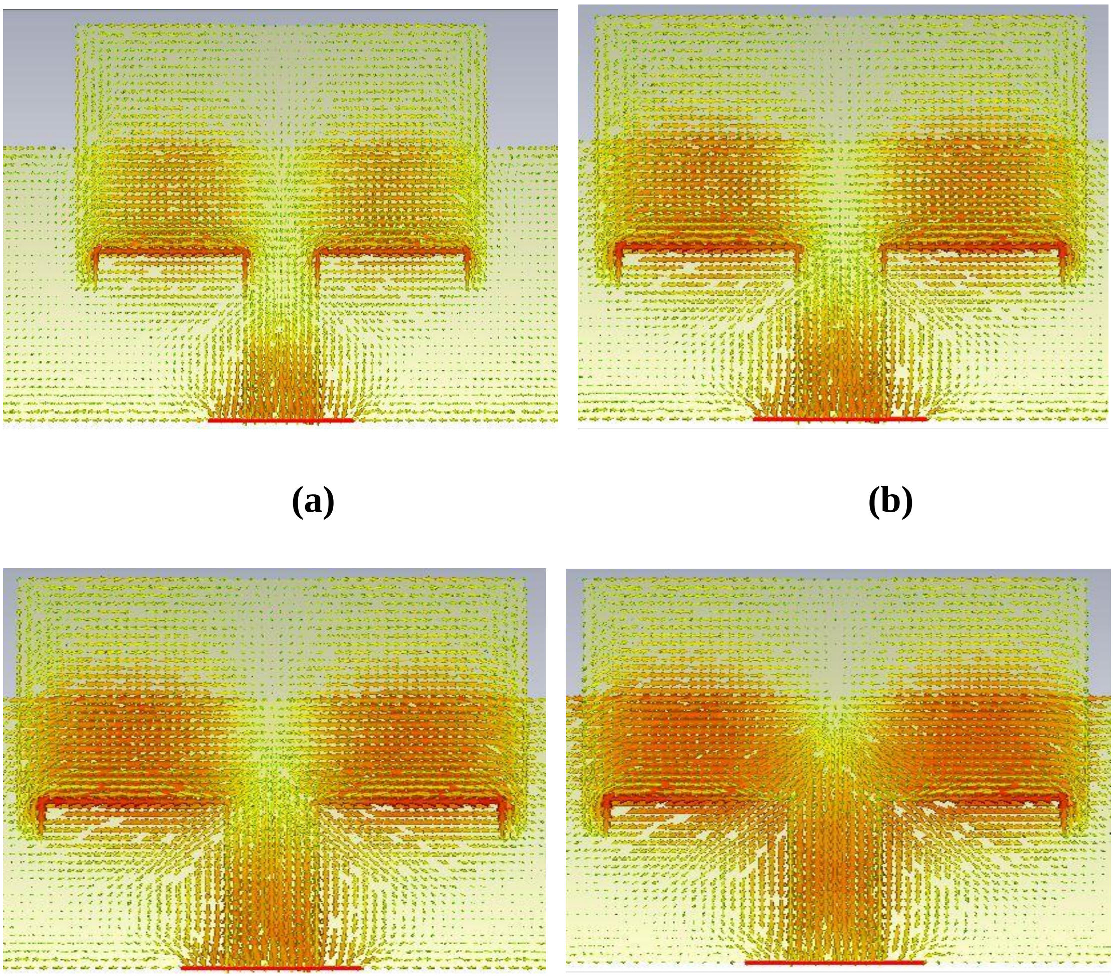


Figure 4.5 (a) Farfield Directivity at phi = 0 for $f_r = 7.24$ GHz

The antenna is found to have good directivity at both the lower and upper resonant frequencies. At 3.05GHz farfield directivity is found to be 4.393dBi whereas at 7.24GHz the farfield directivity of the antenna is 5.516dBi.

4.3.3 Surface current distribution



(a) **(b)**

(b) **(d)**

Figure 4.6 Surface current distribution at different phase (a) 0 (b) 15 (c) 30 (d) 45

In the above figure (Figure 4.6(a), (b), (c), (d)) it can be clearly seen how the surface current distribution changes with time (here four different phase has been taken). In each radiation cycle the current reaches the optimum and energy is radiated into the space as viewed in the radiation pattern plot.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

This thesis gives a detailed analysis of dual band microstrip patch antenna. The proposed antenna is a dual-band microstrip patch antenna whose resonant frequencies are 3.05 GHz and 7.24 GHz. Also the return loss and VSWR are quite appreciable. The maximum gain and directivity is also good and the bandwidth covers good fraction of S band and C band. The upper resonant frequency varies inversely to the inset depth whereas the lower resonant frequency exhibits direct variation. Also there is a direct variation of upper resonant frequency with respect to inset width whereas the lower resonant frequency does not varies. Thus frequency ratio of the proposed antenna is very sensitive to notch dimensions.

5.2 FUTURE SCOPE

The following numerical and experimental investigations may be sought in continuation with the present work :

- Cavity modelling of the proposed design can be done to have a better insight of the normalized fields and the field configurations existing within the dielectric substrate.
- A better MATLAB code can be designed to mathematically analyse the return loss and various other antenna characteristics.
- Various shorting techniques can be tried to load the patch antenna which can further reduce the patch size for a fixed operating frequency.
- Bandwidth enhancement techniques may be looked into to cover the whole of S band and C band that suits various communication standards while retaining the good gain and bandwidth.

Appendix

MATLAB program for studying return loss

```
clc;
clear all;
close all;

epsr=4.3;
epso=8.85*10^(-12);
c=3*10^8;
mu0=4*pi*10^(-7);
mf=10^9;L=.028;W=0.045;
h=0.00456;x0=0.004;
S=0.017;Ln=0.004;
hh=[];vsw=[];freq=[];
epse=((epsr+1)/2)+((epsr-1)/2)*(1+10*h/W)^(-0.5);
C1=((cos(pi*x0/L))^(-2))*epse*epso*L*W/(2*h);

for k=0:0.1:10
 f=k*mf;
L1=1/(C1*(2*pi*f)^2);
Qr=c*(epse^0.5)/(f*h);
R1=Qr/(C1*(2*pi*f));
Q1=0.04598*(0.03+(W/h)^1.23)*(0.272+epsr*0.07);
Cs=0.5*h*Q1*(exp(-1.86*S/h))*(1+4.09*(1-exp(0.785*(h/W)^0.5)));
 del_L=h*mu0*pi*((Ln/L)^2)/8;
 del_C=(Ln/L)*Cs;
L2=L1+del_L;
C2=C1*del_C/(C1+del_C);
Znotch=(1i*(2*pi*f)*R1*L2)/(1i*(2*pi*f)*L2+R1-R1*L2*C2*(2*pi*f)^2);
Scatter=(Znotch-50)/(Znotch+50);
S11=abs(Scatter);
vswr=(1+S11)/(1-S11);
S11_db=20*log10(S11);
hh=[hh S11_db];
freq=[freq k];
end
plot(freq,hh);xlabel('frequency in GHz');ylabel('S parameter magnitude in dB');
```

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