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Master's Degree Thesis

Design of Inset Fed Micro Strip Patch Antenna for Wireless Communication at 2.45GHz

Graduate School of Chosun University

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Advisor: Prof. Dong-You Choi

This thesis is submitted to the graduate school of chosun university in partial fulfillment of the requirements for a master's degree in engineering

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This is to certify that the master's thesis of

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Graduate School of Chosun University

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Acronyms

WLAN	:	Wireless Local Area Network
HFSS	:	High Frequency Structure Simulator
GHz	:	Gigahertz
MHz	:	Megahertz
FR4	:	Flame Retardant
VSWR	:	Voltage Standing Wave Ratio
PCB	:	Printed Circuit Board
ISM	:	Industrial Scientific and Medical
dB	:	decibel
dBd	:	dB (dipole)
dBi	:	dB (isotropic)
RF	:	Radio Frequency

Abstract

Design of Inset Fed Micro Strip Patch Antenna for Wireless Communication at 2.45GHz

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The performance and advantages of micro strip patch antennas such as low weight, low profile, low cost and small size made them the perfect choice for wireless communication system. They have the capability to integrate with microwave circuits and they are well suited for many applications like cell devices, WLAN applications, navigation systems, satellite communications and many others.

The purpose of this thesis is to analysis and design an inset feed, single frequency micro strip patch antenna for wireless communication system at 2.45GHz. Antenna is simulated using Ansoft High Frequency Structure Simulator (HFSS) and fabricated

in laboratory. The rectangular inset fed micro strip patch antenna design uses Flame Retardant 4 FR4, micro strip board with dielectric constant 4.7, scaling factor 0.95 and loss tangent is 0.019. The antenna characteristics such as return loss, radiation pattern, VSWR, gain and bandwidth percentages are measured. The results from the simulation and measurement are presented and compared with each other.

요 약

2.45GHz에서 무선 통신을 위한 삽입된 피드 구조의 마이크로 스트립 패치 안테나의 설계

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마이크로스트립 패치 안테나는 인쇄기판으로 제작하기 때문에 제작이 쉽고, 대량생산에 적합하며 높이가 낮고 견고하다는 등의 여러 가지 특징이 있다. 따라서 무선통신 시스템에 매우 적합한 형태이다. 또한, RF 회로와 쉽게 결합할 수 있으며 휴대장치, WLAN, 네비게이션 시스템, 위성통신 및 다양한 애플리케이션에 적용이 가능하다.

본 논문의 목적은 삽입된 피드구조의 특성을 분석하고, 2.45GHz에서 무선통신 시스템을 위한 단일 주파수 마이크로스트립 패치 안테나를 설계하는 것이다.

안테나 시뮬레이션은 Ansoft사의 고주파 구조 시뮬레이터 (HFSS)를 이용하였으며 실험실에서 직접 제작한 후 측정하였다. 제작한 마이크로

스트립 패치 안테나 설계 조건은 FR-4 기판 유전율 4.7, 스케일링 팩터 0.95, 손실 탄젠트 0.019이며, 제작한 안테나의 반사손실, 방사패턴, VSWR, 이득과 대역폭 등을 분석하였다.

Ⅰ. 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. Since Hertz and Marconi, antennas have become increasingly important to our society until now they are indispensable. They are everywhere: at our homes and work places, on our cars and aircraft, while our ships, satellites and spacecraft bristle with them. Even as pedestrians, we carry them.

A. Overview

Antennas are the key components in the field of any wireless communications. Some of them are parabolic reflectors, patch antennas, slot antennas, and folded dipole antennas with each type of antenna having their own properties and usage. Antennas are the backbone and almost everything in the wireless communication without which the world could not have reached at this age of technology. Micro strip patch antenna are widely used in microwave frequency region because of their computability with printed circuit board (PCB), simplicity in manufacture, inexpensive to fabricate, light in weight and can be made in planar and non-planar surfaces.

B. Objective and scope

The objectives of the research are:

- To design and simulate an inset fed rectangular micro strip patch antenna operating in ISM Band at 2.45GHz for wireless communication.
- To fabricate and measured the characteristics of the designed antennas and comparison between the simulation and measured results.

The scope of this project is to understand the concept of micro strip patch antenna, inset fed transmission line technique. In this research, the single band micro strip antenna using transmission line technique is designed for wireless communication at 2.45GHz (ISM band). The initial simulation results are obtained using High Frequency Structure Simulator (HFSS). The simulator analyzed return loss, radiation pattern, bandwidth, gain, VSWR values. Then the antenna will be fabricated, and results will be measured. We will compare the simulation and measured results.

C. Research methodology

The theoretical and experimental design approach was utilized to optimize the antenna structure, the strategy implemented for simplifying the design and development procedures in this research work can be divided into the following points:

- Initial concept
  - Literature review
  - Design conceptual understanding
- Design and simulation stage
  - Design consideration based on previous research results.
  - Decide the input parameters of the antenna.
  - Design the antenna using antenna design software (HFSS).
- Prototype stage
  - Fabrication of the designed antenna.
- Measurement stage
  - Do measurement of the properties of the fabricated antenna.
- Analysis and conclusion stage
  - Do comparison between measurement results and the simulation results and draw a conclusion.

Figure 1.1 gives the flowchart of design of inset fed micro strip patch antenna.

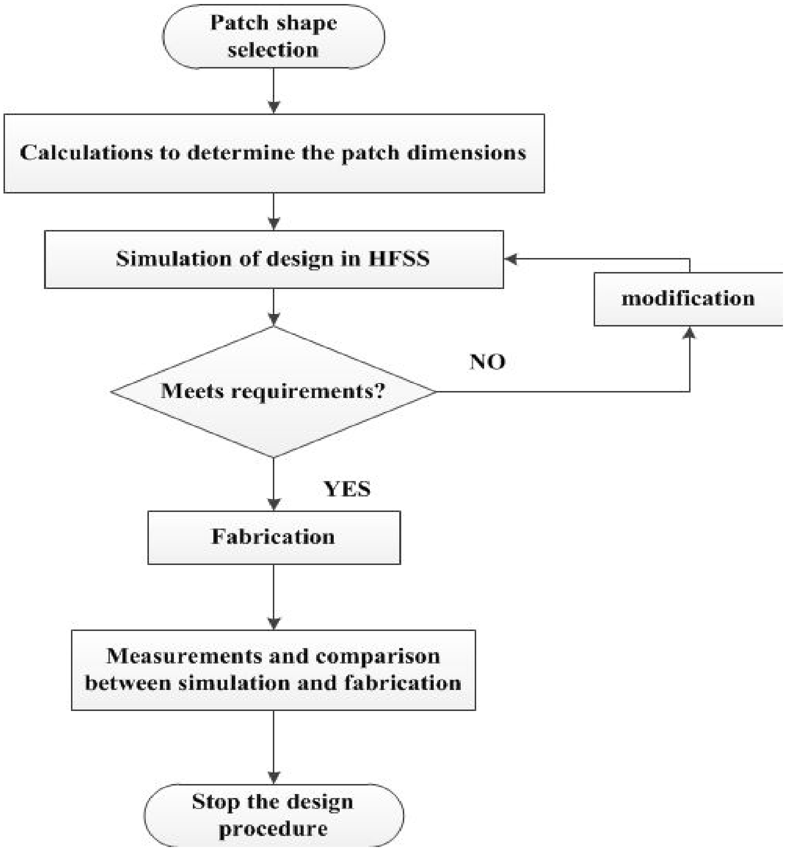


Figure 1.1 Flowchart of design of inset fed micro strip patch antenna

D. Thesis organization

This thesis consists of five chapters describing all the work done in the project. The thesis outline is generally described as follows.

Chapter I: This chapter explains the introduction of the project. Brief general background about antenna is presented. The objectives of the project are clearly phased with detailed. The research scope implementation plan and methodology are also presented.

Chapter II: This chapter discusses some previous literature review of micro strip patch antenna.

Chapter III: This chapter explains the antenna parameters such as gain, input impedance, VSWR and bandwidth.

Chapter IV: This chapter gives an overview of the antenna design methodology with the fundamental process in the design, simulate, fabricate and comparison between simulated and measured value.

Chapter V: This chapter presents the conclusion and future work.

Ⅱ. Literature Review

This chapter presents the basic concepts underlying the research. Among the topics that are discussed are the historical development of micro strip antenna, micro strip antenna overview, its advantages and disadvantages, its applications, type of patches, substrate material, single rectangular patch antenna design, excitation techniques and analytical model of analysis.

A. Historical development of micro strip antennas

Micro strip antennas are a new and exciting technology. In fact, the micro strip antenna can now be considered an established type of antenna that is confidently used by designers worldwide, especially when low-profile radiators are required.

The concept of micro strip antennas was first proposed by Deschamps as early as 1953, Gutton and Bassinot in 1955. However, not much carry-on researches have been carried out until 1972. Since then, it took about twenty years before the first practical micro strip antennas were fabricated in the early 1970's by Munson and Howell. Howell first presented the design procedures for micro strip antennas whereas Munson tried to develop micro strip antennas as low-profile flushed-mounted antennas on rockets and missiles. In addition, research publications regarding the development of micro strip antennas were also published by Bahl and Bhartia and James, Hall and Wood. Dubost has also published a research monograph which covers more specialized and innovative micro strip developments. In fact, all these publications are still in use today.

In October 1997, the first international meeting devoted to micro strip antenna materials, practical designs, array configurations and theoretical models was held at New Mexico State University under co-sponsorship of the U.S. Army Research Office and New Mexico State University's Physical Science Laboratory. In 1997, Hall reported the design idea of electromagnetically coupled patch antenna and proved experimentally that it is able to possess higher bandwidth while maintaining a simple fabrication process. [1]

The early 1980's was not only a crucial point in publications but also a milestone in practical realism and manufacturing of the micro strip antennas. Present day system requirements are an important factor in the development of printed antennas. Since then, antenna researchers began to take an interest in 'antenna array architecture', which has emerged as a dominant approach to the micro strip world.

B. Basic micro strip antenna

In today's aircraft and spacecraft applications where the antenna's size, weight, cost, performance, ease of installation and aerodynamic profile are of at most consideration, the low-profile micro strip antenna is preferred over conventional antennas. The term 'micro strip' actually refers to any type of open wave guiding structure which is not only a transmission line but also used together with other circuit components like filters, couplers, resonators, etc. In fact, micro strip antennas are an extension of the micro strip transmission line. Micro strip antennas can be flush-mounted to metal or other existing surfaces, and they only require space for the feed line, which is usually placed behind the ground plane. As for its disadvantages, micro strip antennas are inefficient and possess very narrow frequency bandwidth, typically only a fraction of a percent or at most a few percent. A micro strip antenna in its simplest configuration consists of a radiation patch on one side of a dielectric substrate, which has a ground plane on the other side. The patch conductors usually made of copper or gold can be virtually assumed to be of any shape. However, conventional shapes are normally used to simplify analysis and performance prediction. The radiating elements and the feed lines are usually photo etched on the dielectric substrate. [2]

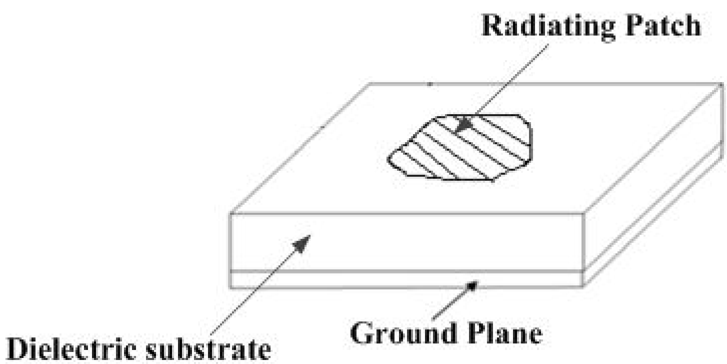


Figure 2.1 Basic configuration of micro strip antenna

The basic configuration of a simple micro strip antenna is shown in Figure 2.1. The upper surface of the dielectric substrate supports the printed conducting strip while the conducting ground plane backs the entire lower surface of the substrate. The radiating patch may be square, rectangular, circular, and elliptical or any other configurations. Square, rectangular and circular shapes are the most common because of the ease of analysis and fabrication. As for the feed line, it is also a conducting strip, normally of a smaller width. [3]

C. Advantages vs. disadvantages of micro strip antennas

The attractiveness of the micro strip antenna method stems from the idea of making use of printed circuit technology. Due to the fact that the micro strip antenna's structure is planar in its configurations, it is able to enjoy all the advantages of a printed circuit board with all of the power dividers, matching networks, phasing circuits and radiators. In addition, as the backside of the micro strip antenna is a metal ground plane, the antenna can be directly placed onto a metallic surface of an aircraft or missile.

Moreover, micro strip antennas have several advantages compared to conventional microwave antennas and therefore, it can accommodate many applications over the board frequency range from 100MHz to 50GHz. Some of the outstanding advantages of the micro strip antennas compared to conventional microwave antennas are shown in Table 2.1.

Table 2.1 Comparison between advantages and disadvantages of the micro strip antennas

Advantages	▪ Light in weight, small in size, low profile planar configurations which can be made conformal. ▪ Low fabrication cost, suitable for mass production ▪ Can be made thin so that the aerodynamics of any aerospace vehicles would not be affected ▪ Can be easily mounted onto missiles, rockets and satellites without much alterations ▪ Low scattering cross section ▪ Possible to achieve linear, circular (left hand or right hand) polarizations with simple changes in feed position ▪ Easy to obtain dual frequency operations ▪ Requires no cavity backing ▪ Compatible with modular designs (solid state devices such as oscillators, amplifiers, variable attenuators, switches, modulators, mixers, phase shifters, etc. can be added directly to antenna substrate board) ▪ Feed line and matching networks are fabricated all together with antenna structure
Disadvantages	▪ Small bandwidth ~0.5 to 10% ▪ Low gain ▪ Most micro strip antennas radiate into half plane ▪ Practical limitations on the maximum gain (~20dB) ▪ Poor end-fire radiation performance ▪ Poor isolation between feed lines and radiating elements ▪ Possibility of excitation of surface waves ▪ Lower power handling capability

D. Applications of micro strip antennas

After analyzing the advantages and disadvantages of the micro strip antennas, it can be observed that its advantages significantly overshadow its disadvantages. Due to the fact that most present day systems demand for small size, lightweight, low cost and low profile antennas, the employment of micro strip technology arises extensively over the years. Even though conventional antennas possess far superior performance over micro strip antennas, it is still clearly disadvantaged by the other properties of the micro strip antennas. Micro strip antennas are particularly suited to those applications where low profile antennas are required. The reason is because it can conform to a given shape easily. Some of typical system applications which employ micro strip technology are shown below.

- Satellite communications
- Doppler and other radars
- Radio altimeter
- Command and control
- Missile telemetry
- Weapon fuzing
- Man pack equipment
- Environmental instrumentation and remote sensing
- Feed elements in complex antennas
- Satellite navigation receiver
- Biomedical radiator

E. Types of patch antennas

There are a large number of micro strip patch antennas. They have been design to match specific characteristics. Some of the common types are shown in Figure 2.2. The most common types are square, rectangular, and circular.

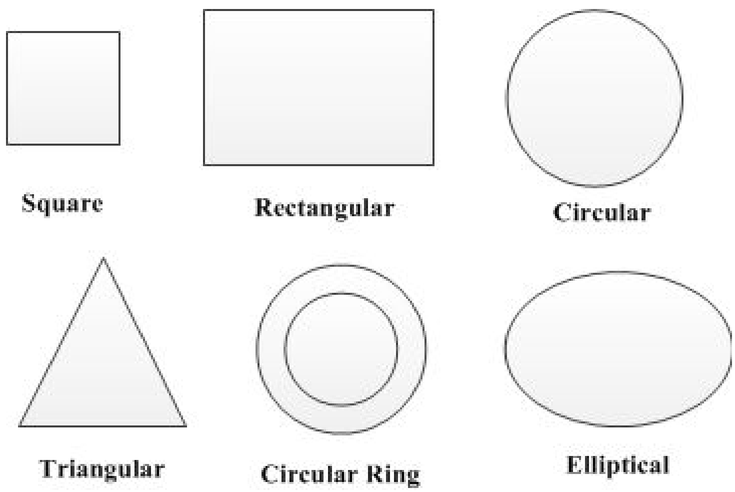


Figure 2.2 The most common shapes of patch antennas

F. Substrate materials

The choice of substrate used is an important factor in the design of a micro strip antenna.

Important qualities of the dielectric substrate include

- The microwave dielectric constant
- The frequency dependence of this dielectric constant which

gives rise to “material dispersion” in which the wave velocity is frequency-dependent

- The surface finish and flatness
- The dielectric loss tangent, or imaginary part of the dielectric constant, which sets the dielectric loss
- The cost
- The thermal expansion and conductivity
- The dimensional stability with time
- The surface adhesion properties for the conductor coatings
- The manufacturability (ease of shaping, cutting and drilling)
- The porosity (for high vacuum applications)

Since the substrate dimensions and dielectric constants are functions of substrate temperature, the operating temperature range becomes an important property in the design of any micro strip antenna. In addition, the dielectric constant and loss tangent are also functions of frequency. As for physical properties which are important in fabrication of the antenna, they are resistance to chemicals, tensile and structural strengths, flexibility, machine ability, impact resistance, strain relief, formability, bond ability and substrate characteristic when clad.

Generally, there are two types of substrates used: soft and hard substrates. Soft substrates are flexible, cheap and can be fabricated easily. However, it possesses higher thermal expansion coefficients. Typical examples of soft substrates are RT Duriod 5870 (ε_r=2.3), RT Duriod 5880 (ε_r=2.2) and RT Duriod 6010.5 (ε_r=10.5). As for hard substrates, it has better reliability and lower thermal expansion coefficients. On the other hand, it is more expensive and non-flexible. Typical examples of hard substrates are quartz (ε_r =3.8), alumina (ε_r=9.7), sapphire (ε_r=11.7) and Gallium Arsenide GaAs (ε_r=12.3).

There are numerous substrates that can be used for the design of micro strip antenna, with their dielectric constants usually in the range of $2.2 \leq \varepsilon_r \leq 12$. The low dielectric constant ε_r is about 2.2 to 3, the medium around 6.15 and high approximately above 10.5. Normally, thick substrates with low dielectric constants are often used as it provides better efficiency, larger bandwidth and loosely bound fields for radiation into space. However, it would also result in a larger antenna size. On the other hand, using thin substrates with higher dielectric constants would result in smaller antenna size. The drawbacks are that it is less efficient and has relatively smaller bandwidths. Therefore, there must be a design trade-off between the antenna size and good antenna performance. [4]

G. Excitation techniques

There are many techniques used to feed or excite micro strip antennas. Four fundamental techniques to feed or excite a micro strip patch antenna are micro strip line, coaxial probe, aperature coupling and proximity coupling.

These can be simplified into direct (micro strip line and probe) and non contact (aperture and proximity-coupled) methods. Some new excitation techniques are being developed, such as the L-shape probe; however, as most micro strip antennas have radiation elements on one side of dielectric substrate, it is therefore necessary to be fed by either a micro strip or coaxial line.

Matching is normally required between the feed line and the antenna. The reason for this is between the antenna input impedances is different from the normal 50Ω line impedance. Matching can be achieved by correctly choosing the position of the feed line. On the other hand, the position of the feed may also affect the radiation characteristics.

1. Micro strip line feed

This method of feeding is very widely used because it is very simple to design and analyze, and very easy to manufacture. Figure 2.3 shows a patch with micro strip line feed from the side of the patch.

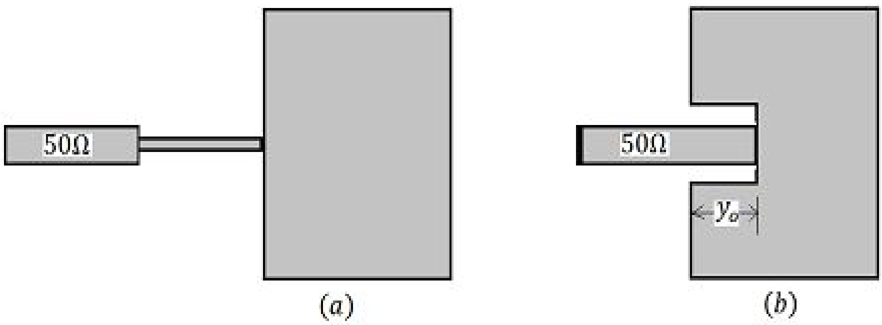


Figure 2.3 Micro strip patch antenna with feed from side

Feeding technique of the patch in figure (2.3a) and figure (2.4) is discussed in [5]. It is widely used in both one patch antenna and multi-patches (array) antennas.

The impedance of the patch is given by [5]:

$$Z_a = 90\frac{\varepsilon_r^2}{\varepsilon_r - 1}\left(\frac{L}{W}\right)^2 \tag{2.1}$$

The characteristic impedance of the transition section should be:

$$Z_T = \sqrt{50 + Z_a} \tag{2.2}$$

The width of the transition line is calculated from [5]:

$$Z_T = \frac{60}{\sqrt{\varepsilon_r}} ln\left(\frac{8d}{W_T} + \frac{W_T}{4d}\right) \tag{2.3}$$

The width of the 50Ω micro strip feed can be found using the equation (2.4) below:

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{reff}}\left[1.393 + \frac{W}{h} + \frac{2}{3} ln\left(\frac{W}{h} + 1.444\right)\right]} \tag{2.4}$$

Where $Z_0 = 50\Omega$

The length of the strip can be

$$R_{in}(x=0) = \cos^2\left(\frac{\pi}{L}x_0\right) \tag{2.5}$$

The length of the transition line is quarter the wavelength

$$l = \frac{\lambda}{4} = \frac{\lambda_0}{4\sqrt{\varepsilon_{reff}}} \tag{2.6}$$

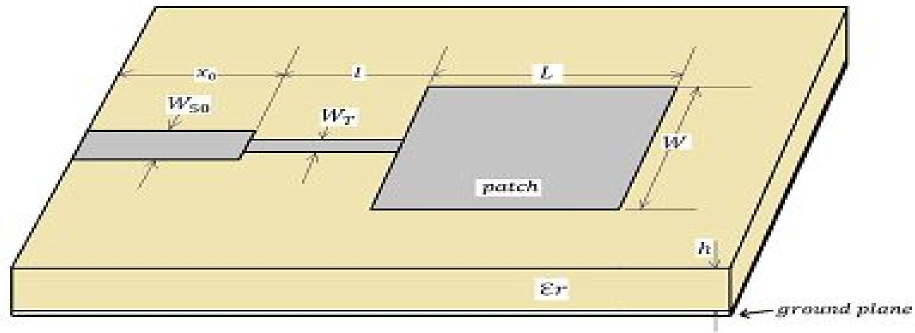


Figure 2.4 Rectangular micro strip patch antenna

2. Coaxial feed (Coplanar feed)

Coupling of the patch antenna through probe is very simple, cheap and effective way. If the designer adjusts the feed point to 50Ω, so he just needs to use a 50Ω coaxial cable with N-type coaxial connector.

The N-coaxial connector is coupled to the back side of the micro strip antenna (the ground plane) and the centre connector of the coaxial will be passed through the substrate and soldered to the patch, as shown in Figure (2.5).

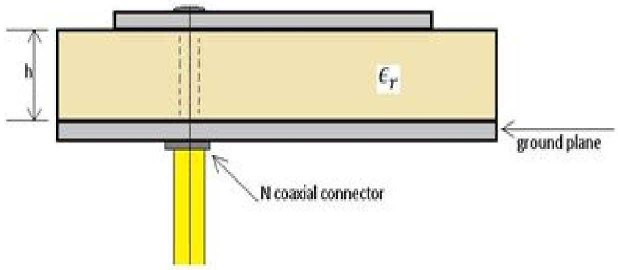


Figure 2.5 Coaxial line feed

3. Aperture coupling

Figure 2.6 shows the layers of the micro strip patch antenna using the aperture mechanism. The ground plane has an aperture in a shape of a circle or rectangular, and separates two substrates: the upper substrate ε_{r1} with the patch on it, and the lower substrate ε_{r2} with the micro strip feed line under it. This type of coupling gives wider bandwidth. Another property of this type is the radiating of the feeding strip line is reduced by the shielding effect of the ground plane. This feature improves the polarization purity [6].

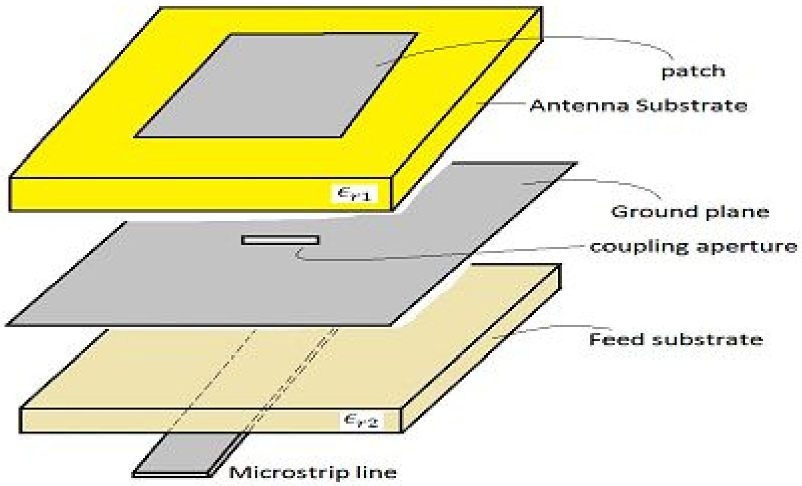


Figure 2.6 Aperture coupling feed method

4. Proximity coupling

Proximity coupling use two substrate ε_{r1} and ε_{r2}. The patch will be on the top, the ground plane in the bottom and a micro strip line is connected to the power source and lying between the two substrates as shown in Figure 2.7. This type is known as “electromagnetically coupled micro strip feed”.

The principle of this mechanism is that the behavior between the patch and the feed strip line is capacitive. Analysis and design of such an antenna is little more complicated than the other ones discussed in the previous sections because the designer has to take into account the effect of the coupling capacitor between the strip feed line and the patch as well as the equivalent R−L−C resonant circuit representing the patch and the calculating of two substrate (ε_{r1} and ε_{r2}). The coupling capacitor of this antenna can be designed for impedance matching of the antenna.

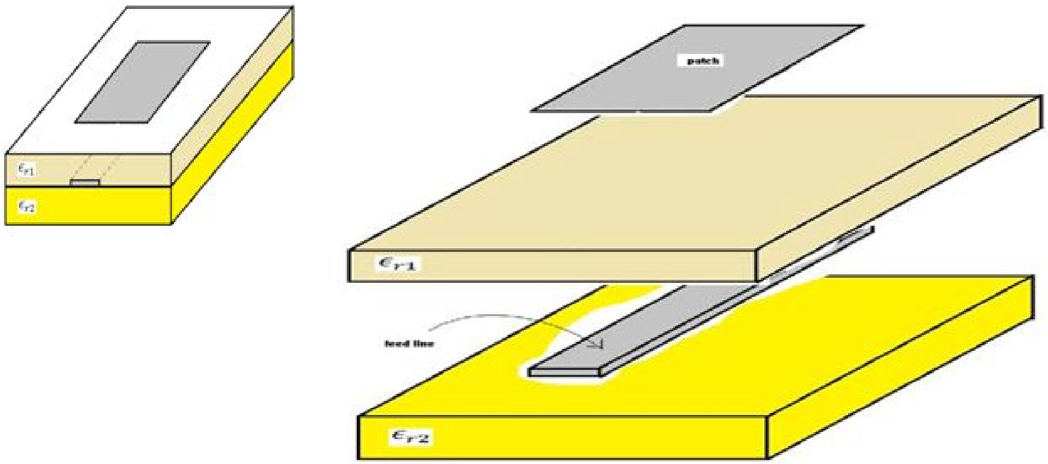


Figure 2.7 Proximity coupling feed method

H. Analytical model of analysis

There are various methods of analysis for micro strip antennas.

The most popular models are the transmission line model, cavity model, and full wave model (which include primarily integral equations/moment method). The transmission line model is the simplest of all and it gives good physical insight but it is less accurate and it is more difficult to model coupling. The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These give less insight as compared to the two models mentioned above and are far more complex in nature. The mainly three models are given below:

- Transmission line model
- Cavity model
- Full wave model

Transmission line model The transmission line model is the easiest of all but it yield the least accurate result and it lacks the versatility. However it does shed some physical insight. Basically the transmission line model represents the micro strip antenna by two slots of width W and height h, separated by a transmission line of length L. The micro strip is essentially non–homogenous line of two dielectrics, typically the substrate and air.

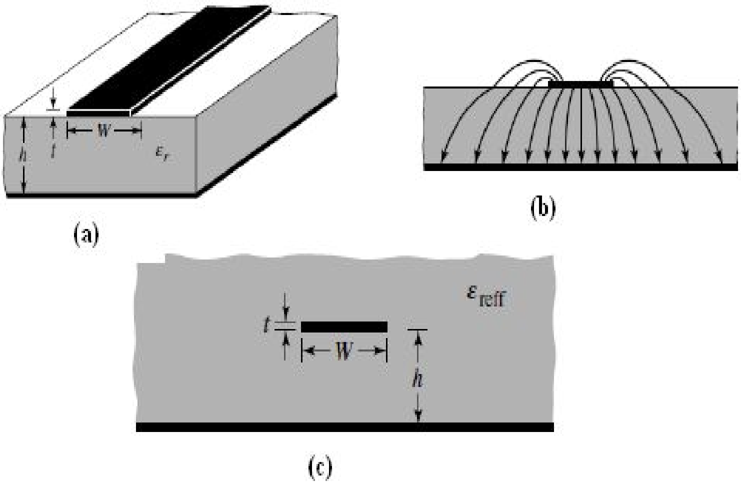


Figure 2.8 Micro strip line and its electric field lines, and effective dielectric constant geometry. [3]

Fringing effect Because of dimension of the patch are finite along the length and width, the fields along the edges of the patch undergo fringing. This is shown in Figure 2.8(b). Hence, as seen from Figure 2.8(b), most of the electric field lines reside in the substrate and parts of some lines in air. As a result, this transmission line cannot support pure transverse electric−magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi−TEM mode. Hence, an effective dielectric constant (ε_{reff}) must be obtained in order to account for the fringing and the wave propagation in the line as shown in Figure 2.8(c). The value of ε_{reff} is slightly less than ε_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are spread in the air as shown in Figure 2.8(b) above. The expression for ε_{reff} is given by:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-\frac{1}{2}} \tag{2.7}$$

Where ε_{reff}=Effective dielectric constant

ε_r=Dielectric constant of substrate

h=Height of dielectric substrate

W=Width of the patch

Consider Figure 2.9, which shows a rectangular micro strip patch antenna of length L, width W resting on a substrate of height h. The co-ordinate axis is selected such that the length is along the x direction, width is along the y direction and the height is along the z direction.

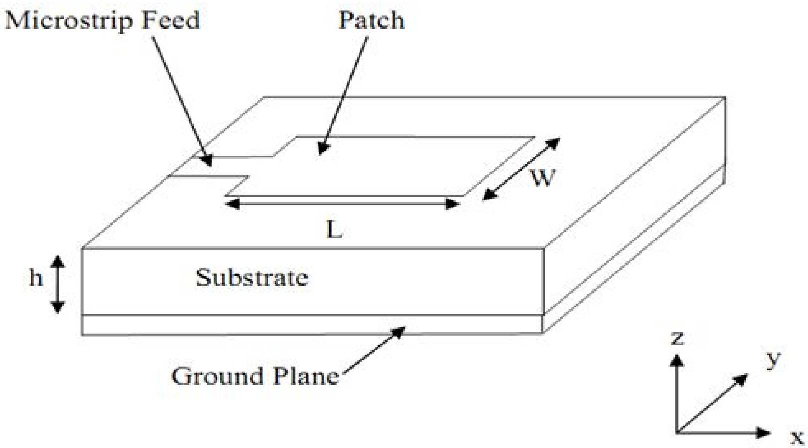


Figure 2.9 Micro strip patch antenna

In the Figure 2.10(a) shown below, the micro strip patch antenna is represented by two slots, separated by a transmission line of length L and open circuit at both the ends. Along the width of the patch, the voltage is maximum and the current is minimum due to the open ends. The fields at the edges can be resolved into normal and tangential components with respect to the ground plane. It is seen from Figure 2.10(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 cancel each other in the broadside direction. The tangential components (Figure 2.10), which are in phase, means that the resulting fields combine to give maximum radiated field normal to the surface of the structure.

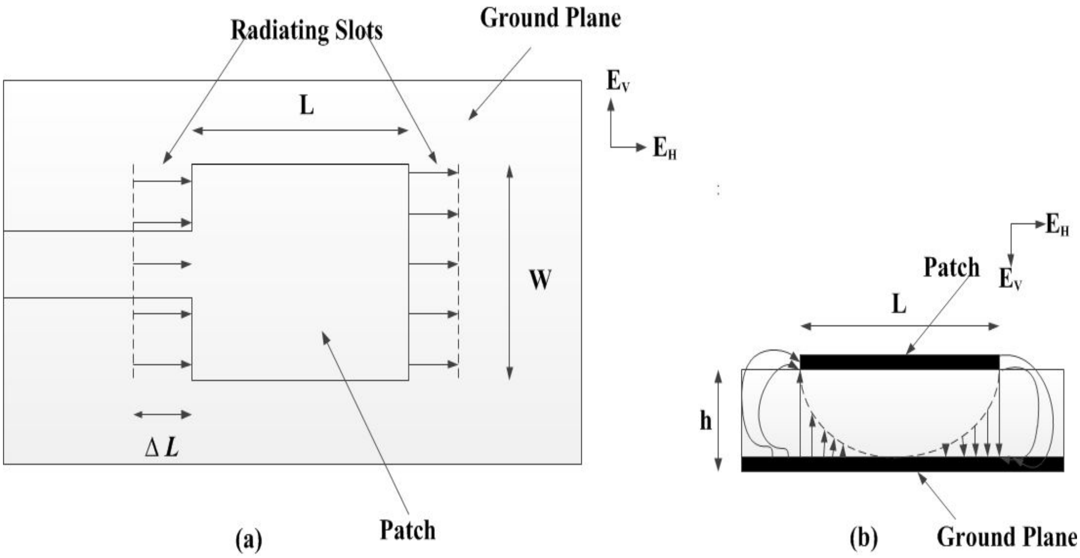


Figure 2.10 Top and side view of antenna

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 micro strip antenna looks greater than its physical dimensions. So the dimensions are changed and extended a bit for a better performance i.e. it has been extended by ΔL, E_H

ΔL is calculated as below [7]:

$$\triangle L = 0.412h \frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{2.8}$$

L_{eff} the effective length of the patch is given by:

$$L_{eff} = L + 2\triangle L \tag{2.9}$$

For the particular resonate frequency the effective length of the patch is calculated by :

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{2.10}$$

Considering the rectangular patch micro strip antenna the resonating frequency for the mode TM_{mn} is given by [8]

$$f_0 = \frac{c}{2\sqrt{\varepsilon_{reff}}}\left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2\right] \tag{2.11}$$

m, n are the operating modes of the micro strip patch antenna. For the effective radiation the design of the structure is the utmost important aspect and for this the width is calculated as [7]:

$$W = \frac{c}{2f_0}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{2.12}$$

Ⅲ. Antenna Parameters

A. 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=0dB) in all directions, since all of the power delivered to it is radiated equally well in all directions.

Although the isotropic is 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=2.15dB) 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

$$G_{dBd} = G_{dBi} - 2.15dB \tag{3.1}$$

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.

B. 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.

C. 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 50Ω or 75Ω 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.

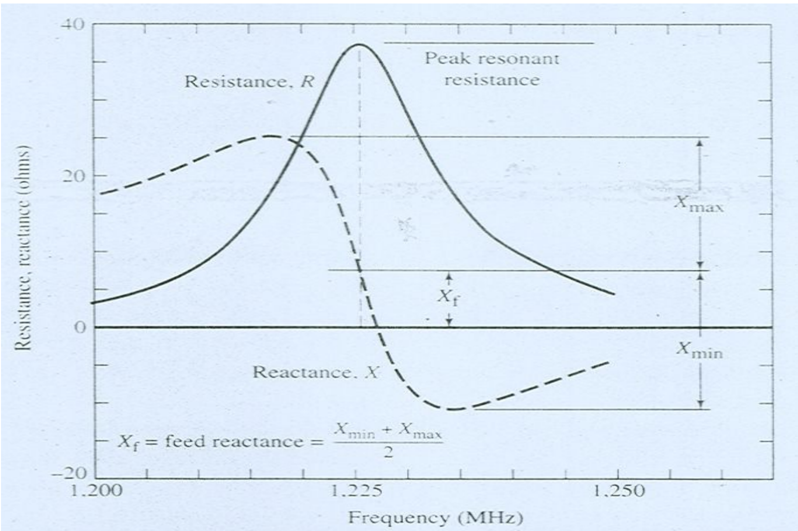


Figure 3.1 Typical variation of resistance and reactance of rectangular micro strip antenna versus frequency [9]

D. 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.

As stated above and elsewhere, an ideal match between the antenna and transmission line is desired; but this can often be achieved only for a single frequency. In practice, an antenna may be used for an entire frequency band, and its terminal impedance will vary across the band. In an antenna specification, either the impedance versus frequency across a band is given or the VSWR versus frequency is given.

E. 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 narrow band antennas, the bandwidth is expressed as a percentage of the bandwidth.

$$BW_{broadband} = \frac{f_H}{f_L} \tag{3.2}$$

$$BW_{narrowband}(\%) = \left[\frac{f_H - f_L}{f_c}\right] \times 100 \tag{3.3}$$

When the ratio $\frac{f_H}{f_L} = 2$ the antenna is said to be broadband. The antenna's performance can be judged by observing VSWR, when VSWR≤2 (RL≥−9.5dB) the antenna is said to have performed well.

Ⅳ. Micro Strip Patch Antenna Design

In this chapter, the procedure for designing a rectangular micro strip patch antenna is explained. Next, a compact rectangular micro strip patch antenna is designed in HFSS (ver.10) for use in wireless communication. Then simulated antenna is fabricated on PCB board. Finally, the results obtained from the simulations and fabricated results are compared.

A. Design specifications

The three essential parameters for the design of a rectangular Micro Strip Patch Antenna:

- Frequency of operation (f_0): the resonant frequency selected for design is 2.45GHz.
- Dielectric constant of the substrate (ε_r): the dielectric material selected for design is FR4 which has a dielectric constant of 4.7.
- Height of dielectric substrate (h): the height of the dielectric substrate is selected as 1.6mm.

Hence the essential parameters for the design are:

- f_0=2.45GHz
- ε_r=4.7
- h=1.6mm

The following Table 4.1 gives us the design parameter specification of micro strip antenna.

Table 4.1 Design specifications of micro strip patch antenna

Type of the antenna	Rectangular Patch antenna
Dielectric constant of the substrate	4.7 (FR4)
Operating frequency	2.45GHz
Height of the substrate	1.6mm
Feeding method	Microstrip line feed
Polarization	Linear
Dielectric loss tangent (tanδ)	0.019

B. Design procedure

The design steps of this patch can be found in [10,11] and many other electromagnetic textbooks. The aim is to determine this patch's feed tolerances and its performance. The procedure for designing such a patch is summarized in the following section.

Step1: Calculation of the width (W):

The width of micro strip patch antenna is given as:

$$W = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{4.1}$$

Substituting $c=3\times10^8$m/s, $\varepsilon_r=4.7$ and $f_0=2.45$GHz, we get: W=36.26mm

Step 2: Calculation of effective dielectric constant (ε_{reff}):

The effective dielectric constant is equal to:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-\frac{1}{2}} \tag{4.2}$$

Substituting ε_r=4.7, W=36.26mm and h=1.6mm, we get: ε_r=4.345

Step 3: Calculation of the effective length (L_{eff}):

The effective length is:

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{4.3}$$

Substituting ε_{reff}=4.345, c=3×10^8m/s, and f_0=2.45GHz, we get: L_{eff} =29.37mm

Step 4: Calculation of the length extension ($\triangle L$):

The length extension is :

$$\triangle L = 0.412h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{4.4}$$

Substituting ε_{reff}=4.345, W=36.26mm and h=1.6mm, we get:$\triangle L$ =0.732mm

Step 5: Calculation of actual length of patch (L):

The actual length is obtained by:

$$L = L_{eff} - 2\triangle L \tag{4.5}$$

Substituting L_{eff}=29.37mm and $\triangle L$=0.732mm, we get: L=27.90mm

Step 6: Calculation of the ground plane dimensions (L_g and W_g):

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. Hence, for the design, the ground plane dimensions would be approximately given as: L_g and W_g=150mm

Step 7: Determination of Inset feed depth (Y_0):

An inset fed type is to be used in this design. The inset feed introduces a physical notch, which in turn introduces a junction capacitance as shown in Figure 4.1. The physical notch and its corresponding junction capacitance influence the resonance frequency. As the inset feed-point moves from the edge toward the centre of the patch the resonant input impedance decreases monotonically and reaches zero at the centre. When the value of the inset feed point approaches the centre of the patch, the $\cos^2 \frac{\pi}{L} Y_0$ where Y_0 is inset distance, which varies very rapidly; therefore the input resistance also changes rapidly with the position of the feed point. To maintain very accurate values, a close tolerance must be preserved [12-14]. In this thesis, the value of inset fed distance Y_0 is 7.5mm and the length and width of transmission line at 50Ω is 32mm and 3mm respectively [15].

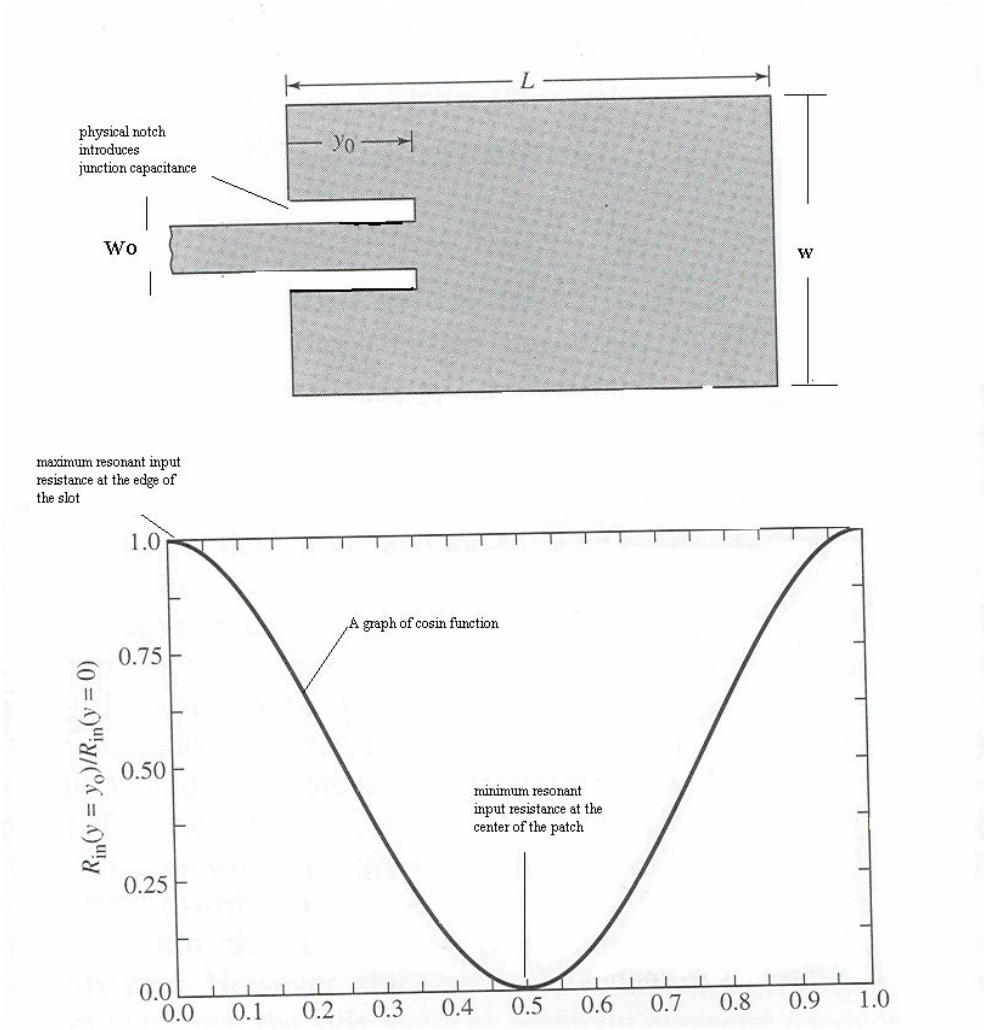
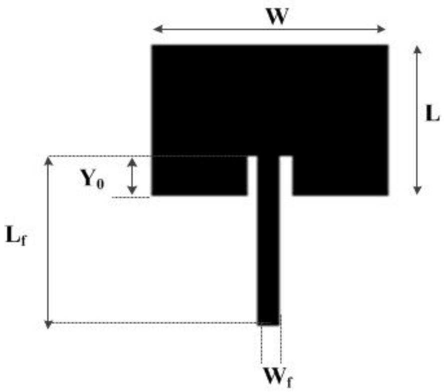


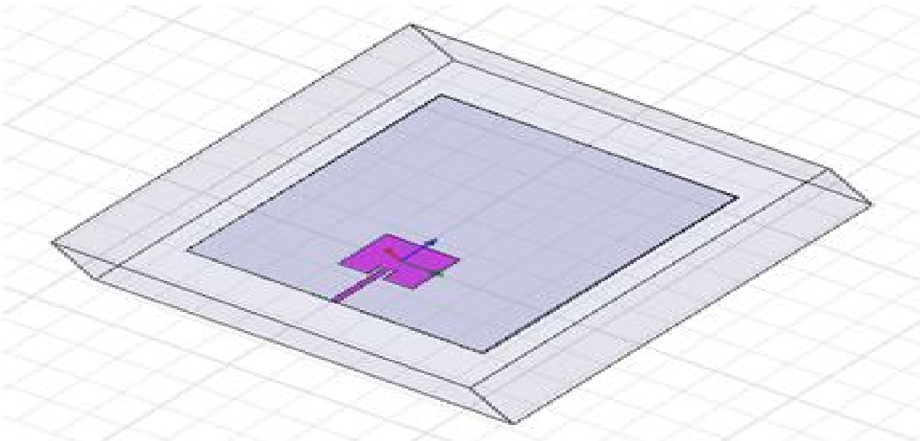
Figure 4.1 Micro strip line inset feeding and variation of normalized input resistance [10]

C. Simulation setup and results

The software used to model and simulate the micro strip patch antenna is Ansoft HFSS [16]. Ansoft HFSS is a high performance full-wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device, having microsoft windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment where solutions to your 3D EM problems are quickly and accurately obtained. It employs the Finite Element Method (FEM), adaptive meshing, and brilliant graphics to give you unparalleled performance and insight to all of your 3D EM problems. Ansoft HFSS can be used to calculate parameters such as S-parameters, resonant frequency, and radiation pattern. The design inset feed rectangular micro strip patch antenna at 2.45GHz for wireless communication having previous calculated value of length L, width of the patch W, inset fed distance Y_0 and transmission line length L_f as shown in Figure 4.2 (a). The designed antenna in HFSS simulator is shown in Figure 4.2 (b).



(a)



(b)

Figure 4.2 Design antennas in HFSS

During the process of the design of the patch antenna there is a response taken from the magnitude of S_{11} vs. the frequency (this is known as the return loss). The simulated return loss of the design antenna is −31.07dB at center frequency of 2.45GHz as shown in Figure 4.3. And has 60MHz bandwidth at −10dB (the difference of 2.48GHz and 2.42GHz).

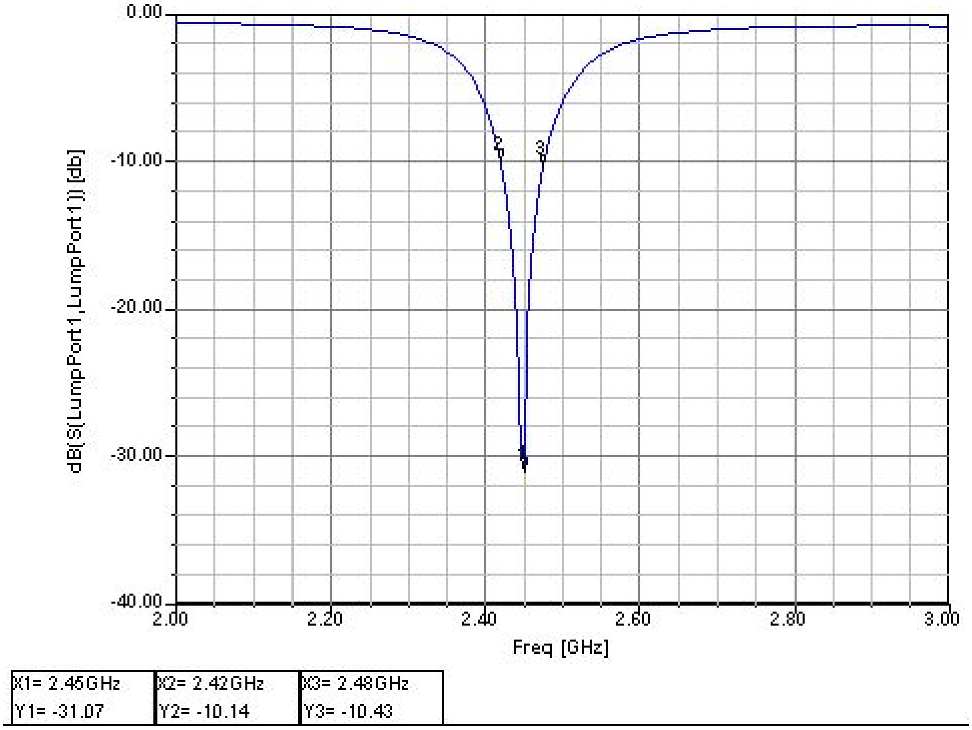


Figure 4.3 Return loss vs. frequency

The bandwidth of the antenna in term of percentage is defined by

$$BW = \frac{f_{\max} - f_{\min}}{f_r} \times 100\% \qquad (4.6)$$

Where $f_{\max}$ and $f_{\min}$ are determined at -10dB. f_r is the resonance frequency. The simulated value at -10dB, $f_{\max}=2.48$, $f_{\min}=2.42$ and the bandwidth percentage is 2.44%.

The VSWR characteristic of the antenna should falls in between 1 to 2. From simulation its value is 1.06 at 2.45GHz as depicted in Figure 4.4.

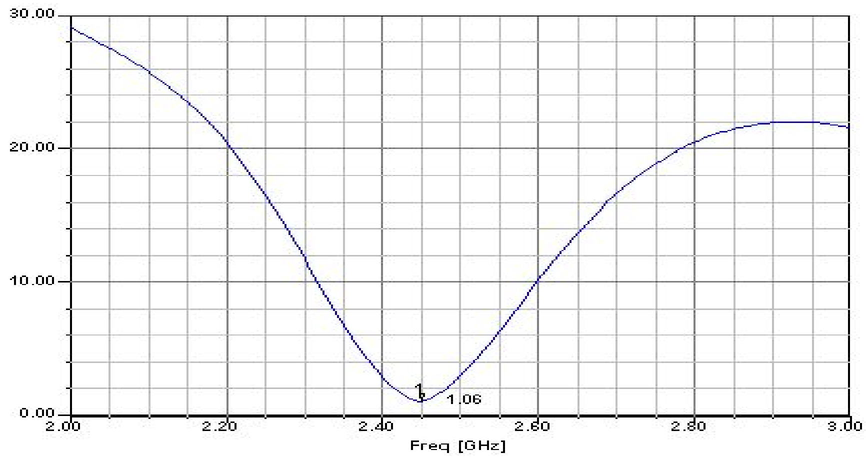


Figure 4.4 VSWR vs. frequency

The radiation pattern of the antenna obtained is shown in figure 4.5 at phi =90°(red) and phi=0°(blue) at 2.45GHz. The gain of the antenna is 3.41dB shown in Figure 4.6.

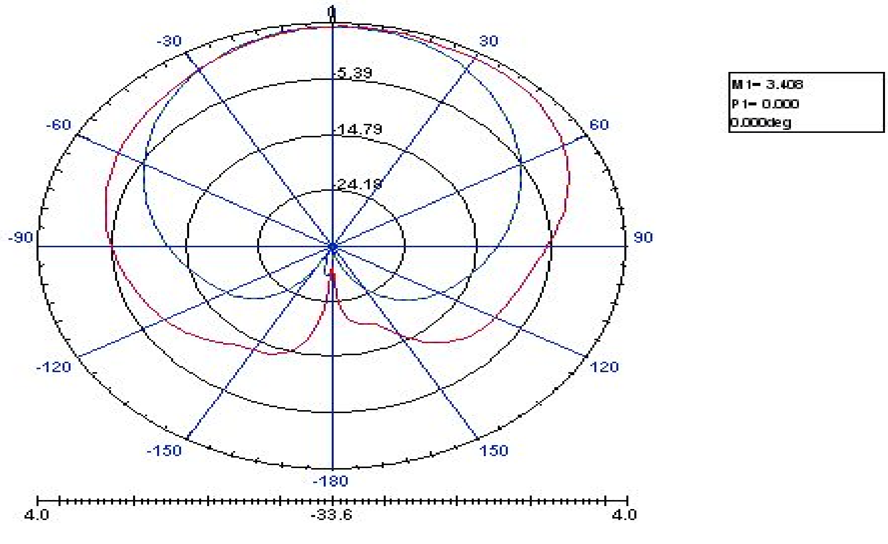


Figure 4.5 Radiation pattern at 2.45GHz

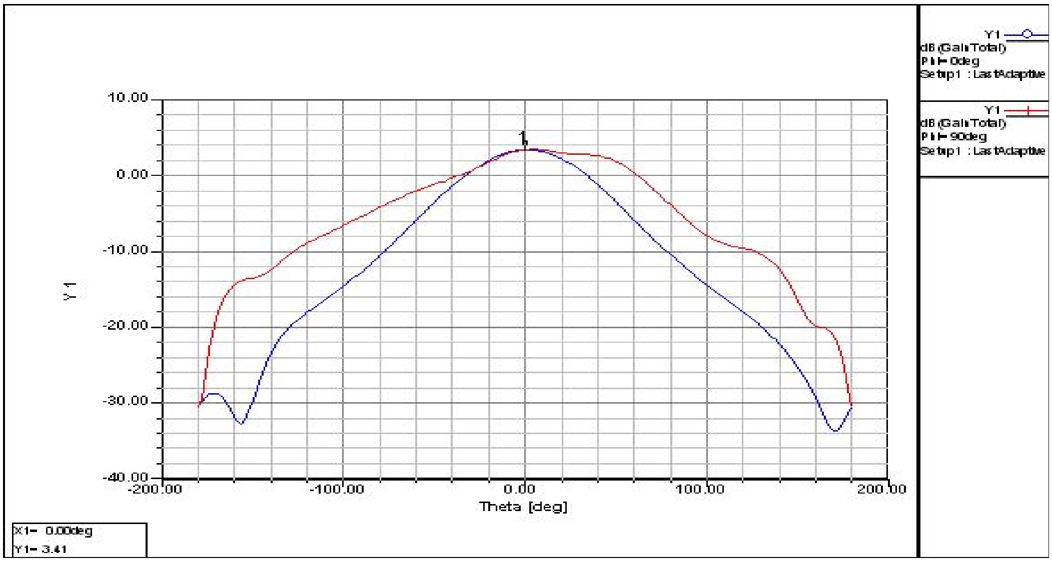


Figure 4.6 Gain of antenna

The scattering parameter for the antenna design at 2.45GHz on the smith chart is shown in Figure 4.7.

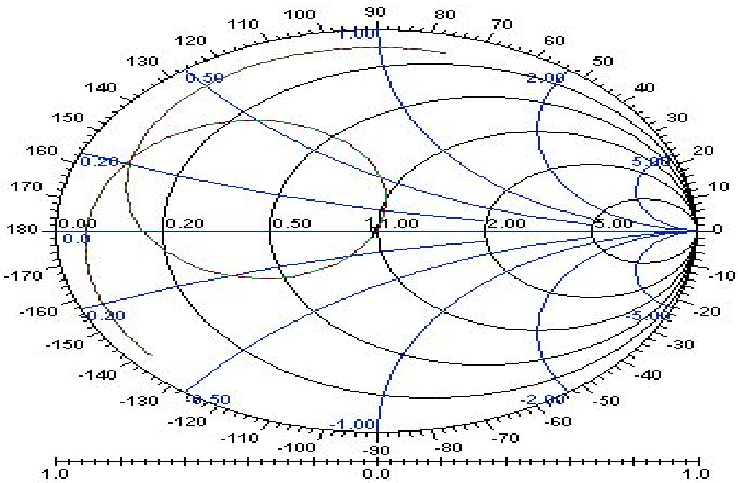


Figure 4.7 Smith chart at 2.45GHz

D. Fabrication procedure and its results

Simulated inset fed micro strip rectangular patch antenna is fabricated on FR4 PCB. During fabrication process, the layout is made on a transparency paper by printing it using AutoCAD 2007. After layout has been prepared, the transparency is placed together on FR4 PCB and exposed to light. The layout is made visible by using developer chemical into the first tray. In second tray, etching process has been done. Then the fabrication process is completed by wiping the PCB with thinner.

The measurement setup is done by using Agilent Technologies N5230A 10MHz−40GHz PNA−L−Network Analyzer as shown in Figure 4.8. And Agilent Technologies: N9912A is also used to measure the values.

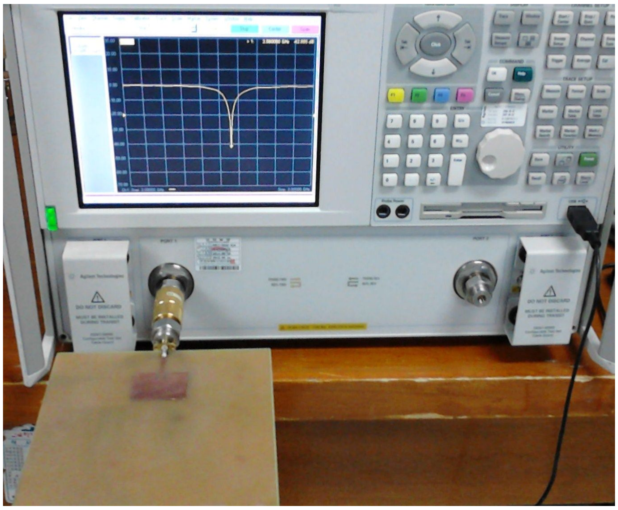


Figure 4.8 Measurement setup of inset fed patch antenna

The measured return loss is obtained to be 34.96dB at 2.545GHz as in Figure 4.9. The measured value at −10dB, f_{max}=2.575GHz, f_{min}=2.515GHz are shown in Figure 4.10 and 4.11, BW=60MHz and the bandwidth percentage is 2.44%.

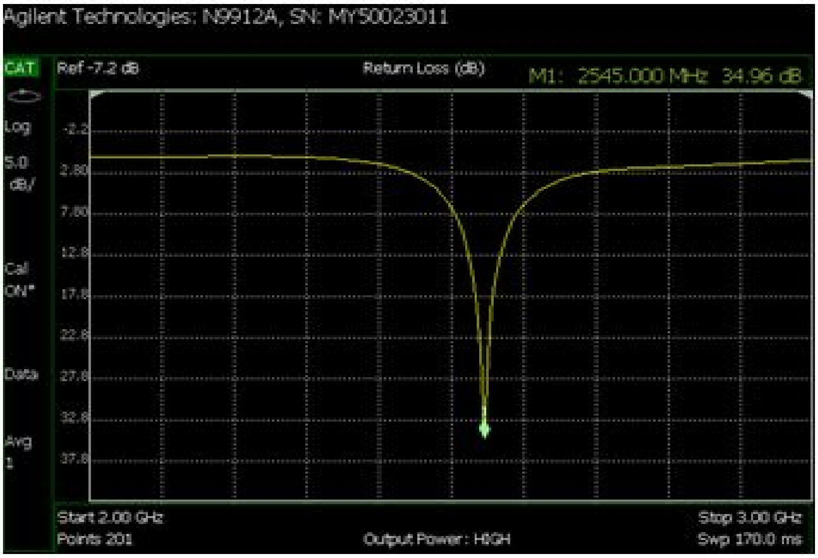


Figure 4.9 Measured return loss vs. frequency

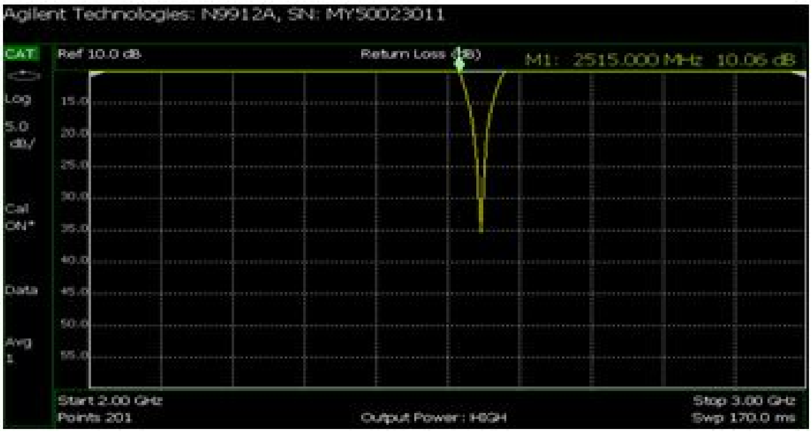


Figure 4.10 Frequency measured at −10dB, f_{min} is 2.515GHz

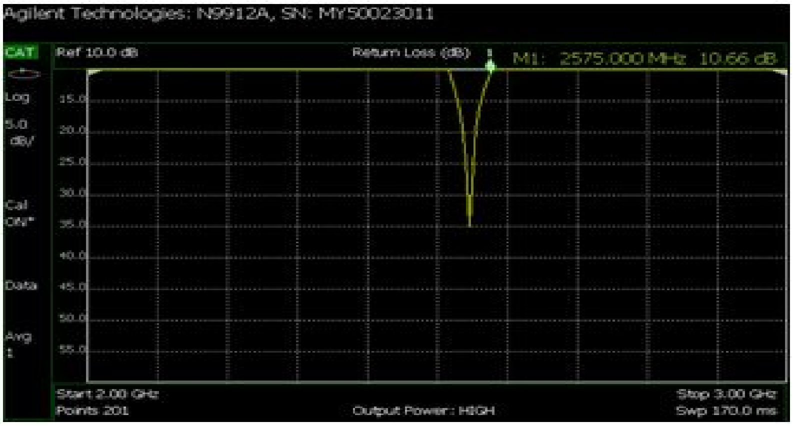


Figure 4.11 Frequency measured at −10dB, f_{max} is 2.575GHz

The measured VSWR is 1.07 at 2.545GHz as shown in Figure 4.12.

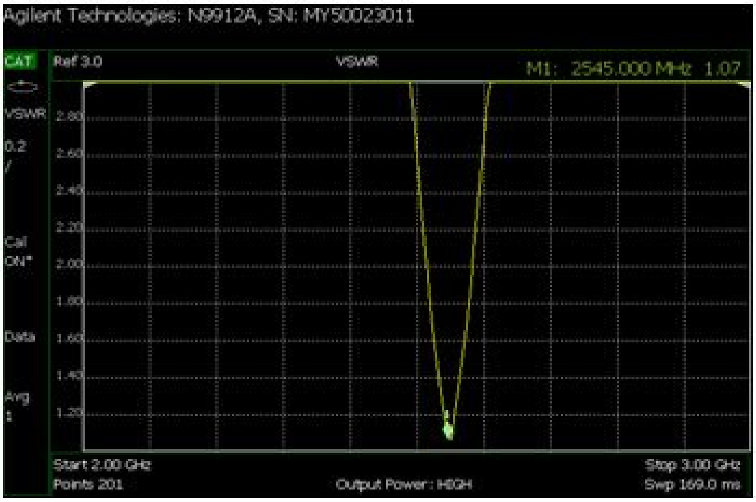


Figure 4.12 Measured VSWR vs. frequency

The measured impedance matching at 50Ω by using Agilent Technologies N5230A 10MHz−40GHz PNA−L−Network Analyzer is shown in Figure 4.13.

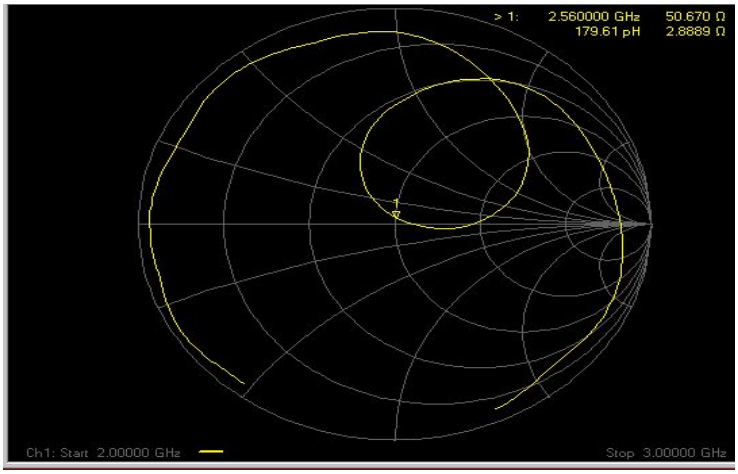


Figure 4.13 Impedance matching measured at 50Ω

The resonant frequency has shifted from the designed frequency 2.45GHz. The reason of the shift may be due to the FR4 board has ε_r that varies from 4.7 to 4.9. In physical design of antenna, a material having varying ε_r, length, width and thickness of board may affect in shifting of resonant frequency. And also other factors may have affect such as chemical used in etching accuracy, surface finish. The difference between simulated and fabricated measured value is shown in Table 4.2.

Table 4.2 Comparison between simulation and fabricated measured results

Result	Resonant frequency (GHz)	Return loss (dB)	VSWR
Simulation	2.45	-31.07	1.06
Measurement	2.545	-34.96	1.07

Comparison of electrical parameters of different antennas are shown in Table 4.3.

Table 4.3 Comparison of electrical parameters of different antennas

Parameter	Antenna # 1	Antenna # 2	Antenna # 3 (our antenna)
Frequency (GHz)	10	2.4	2.45
Substrate	Taconic TLC	RO4003C	Flame Retardant (FR4)
Dielectric constant	3.2	3.4	4.7
Simulator used	HFSS	IE3D	HFSS Ver.10
Thickness of the dielectric	0.79mm	1.524mm	1.6mm
Dimensions	L=8.27mm W=10.35mm	L=30mm W=21mm	L=27.90mm W=36.26mm
Band width	-	-	60MHz(2.44%)
Return loss(dB)	-27.34	-15.72	-31.07
VSWR	1.08	-	1.06
Gain(dB)	6.94	5.1	3.41dB

Note:

Antenna # 1 : Rectangular Patch with Taconic TLC dielectric substrate [17]

Antenna # 2 : Rectangular Patch with RO4003C dielectric substrate [18]

Antenna # 3 : Rectangular Patch with FR4 dielectric substrate

V. Conclusion and Future Works

In this thesis, the mathematical calculation for design of inset fed rectangular patch antenna at 2.45GHz is presented. Simulation of inset fed micro strip patch antenna is done in HFSS version 10. The antenna performance characteristics such as return loss, VSWR, gain, radiation pattern and impedance matching are obtained in simulation. The simulated antenna is then fabricated in FR4 PCB board. The fabricated antenna frequency is compared with the simulated resonance frequency. It is found to be slight difference than simulated value as in real world physical parameter may not be exactly same. From simulation, the return loss obtained is -31.07dB at 2.45GHz, VSWR is 1.06 and gain is 3.14dB. From fabrication, the return loss obtained is -34.96dB at 2.545GHz and VSWR is 1.07.

Hence, the method of designing the micro strip patch antenna is studied theoretically and is implemented practically using HFSS simulator and FR4 PCB board. Thus, the idea of antenna design concept has been achieved.

For future work, we can design inset fed patch array antenna which will increase the gain of antenna. The antenna design in this thesis is single band, for future we can design multiband. By using the mathematical calculation, we can design coaxial fed micro strip rectangular patch and array antenna.

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