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SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

Performance comparison of coplanar /Micro strip Antenna for X-band, S-band and C-band applications using coplanar waveguide (CPW) feed technique

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I, undersigned and declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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ABSTRACT

Merits of planar antennas make them a potential candidate for the field of communication in Microwave application. This thesis presents performance comparison of Coplanar /Micro strip patch Antenna for microwave X-band, S-band and C-band applications using coplanar waveguide feed technique. As coplanar waveguide feeding has wider bandwidth and high radiation efficiency it could be applicable in many X- band, S-band and C- band applications.

The substrate applied in the design process for both coplanar and microstrip patch antenna is FR4 Epoxy Glass, which has relative permittivity of 4.4 and substrate height 1.6mm. Antenna measurements such as, bandwidth efficiency, radiation pattern and radiation efficiency are conducted and the performances are compared. Antenna simulations have been performed by using Ansoft HFSS TM V13.0, which is a Finite Element Method (FEM) based electromagnetic solver. Simulation results are presented in terms of Resonant Frequency Return Loss, Radiation Pattern and the antenna Gain.

It has been found that microstrip patch antennas have lower return loss and are more directive than coplanar patch antenna. The simulated results have also shown that coplanar patch antennas have high radiation efficiency and comprises of a wider bandwidth as compared to a microstrip patch antennas. The radiation efficiency obtained for microstrip patch antenna ranges from 82.342% to 89.231% and that for coplanar patch antenna is 92.31% to 98.78%. Meanwhile, the directivity for microstrip patch antenna ranges from 5.352dB to 7.65dB and that for a coplanar patch antenna is 2.79dB to 5.69dB.

Keywords: *Coplanar patch antennas, Microstrip patch antennas, gain, return loss,, inset*

CONTENTS

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I also like to thank my family who has always stood as sources of encouragement.

LIST OF ABREVATIONS

FEM	Finite Element Method
GSM	Global System for Mobile communication
HFSS	High Frequency Simulator
IC	Integrated Circuit
IEEE	Institute of Electric and Electronics Engineering
LAN	Local Area Network
MMICs	Monolithic Microwave Integrated Circuits
PCB	Printed Circuit board
PCS	Personal Communications Services
RF	Radio Frequency
RL	Return Loss
SHF	Super High Frequency
TEM	Transverse Electromagnetic
UHF	Ultra-High Frequency
UMTS	Universal Mobile Telephony system
VSWR	Voltage Standing Wave Ratio
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

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Chapter 1

Introduction

1.1 Overview

Smaller size and wider bandwidth are key requirement for recent developments in communication system for designing a radiating element (antenna). In communication engineering, 7.0 to 11.2 GHz frequency band is set for X band application. The S-band is part of the microwave band of the electromagnetic spectrum. It is defined by an IEEE for radio waves with frequencies that range from 2 to 4 GHz, crossing the conventional boundary between UHF and SHF at 3.0 GHz. The S band is used by weather radar, and surface ship radar.

The C-band is a name given to certain portions of the electromagnetic spectrum, including wavelengths of microwave that are used for long distance telecommunications. C-band (4 to 7 GHz) and its slight variations contain frequency ranges that are used for, some Wi-Fi devices, some cordless telephones, and some weather radar systems.

A coplanar patch antenna is a structure in which all the conductors supporting wave propagation are located on the same plane, i.e. generally the top of a dielectric substrate. Coplanar Waveguide is composed of a median metallic strip separated by two narrow slits from an infinite ground plane. The characteristic dimensions of a CPW are the central strip width W and the width of the slots s. The structure is symmetrical along a vertical plane running in the middle of the central strip.

A micro strip patch antenna is fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate, such as a printed circuit board, with a continuous metal layer bonded to the opposite side of the substrate which forms ground plane substrates.

1.2 Statement of the problem

For high performance communication applications like WiMAX, WLAN, Mobile Radio and wireless Communication Systems size, cost, weight, ease of fabrication and ease of installation offer constraints.

The increasing popularity of indoor wireless LAN capable of high speed transfer rate requires the development of efficient planar patch antennas. Due to increased usage in residential and office areas, these systems are required to be low profile, aesthetically pleasing and low cost as well as highly effective and efficient. Planar patch antennas are well suited for wireless LAN application systems due to their versatility, conformability, low cost and low sensitivity to manufacturing tolerances. Recently importance has been placed upon creating patch antennas that show broadband properties and capable of high speed data transfer.

Thus, this thesis will be directed to design both micro strip and coplanar patch antennas which will be applicable for X band, C band and S band applications and put the most suitable antenna forward for the aforementioned communications in Microwave application systems.

1.3 General Objective

The general objective of this thesis is to do performance comparison of coplanar /Micro strip Antenna for X-band, S-band and C-band applications using coplanar waveguide feed technique.

1.3.1 Specific Objective

The specific objectives of this thesis are:

- Design a rectangular shaped coplanar and micro strip planar antenna, which would be applicable in microwave X band, S band and C band applications, by applying a complete mathematical calculations and taking design factors into considerations so as to optimize the different antenna parameters.
- Evaluate performance using antenna simulation tool Ansoft HFSS.
- Perform parametrical analysis so as to compare one patch antenna against the other using the different antenna parameters.
- Propose which patch antenna would be more suitable for microwave X band, S-band and C- band applications based on the result.

1.4 Methodology

- Using design parameters, the two antennas are designed for the different frequency ranges using design considerations and procedures. The selected frequencies for both antennas are going to be 2.4GHz, 3.5GHz, 6GHz, 7GHz, and 10.5GHz.
- Model the two antennas using HFSS.
- Simulating and optimizing design parameters.
- Finally comparison and result validation will be done.

1.5 Thesis Outline

This thesis is organized as follows: Chapter two is about the theoretical background of Coplanar and microstrip planar antennas. Chapter three is about antenna design procedure of rectangular micro strip and coplanar patch antennas using coplanar waveguide feed feeding technique. Chapter four presents and discusses: simulation results for the proposed antennas and compare performances of the two patch antennas in terms of antenna characteristics such as return loss (dB), radiation pattern, gain and radiation efficiency. Chapter five is about thesis conclusion and recommendation for future work.

1.6 Literature review

This section gives a detailed review of different technologies and designs adopted by different researchers in the case of printed antennas for compact and multiband applications. Different techniques for broadband and multiband designs that have been reported recently are also highlighted. A number of papers on compact multiband antennas are reviewed here.

Wireless communications have progressed very rapidly in recent years, and many mobile units are becoming smaller in size. To meet the miniaturization requirement, compact antennas are required. Planar printed antennas have the attractive features of low profile, small size and conformability to mounting hosts. They are very promising candidates for satisfying the above applications. For this reason, compact and broadband design techniques for planar antennas have attracted much attention from antenna researchers [1].

Very recently, especially after the year 2000, many novel planar antenna designs to satisfy specific bandwidth specifications of present-day mobile cellular communication systems, including the global system for mobile communication (GSM: 890–960MHz), the digital communication system (DCS: 1710–1880MHz), the personal communication system (PCS: 1850–1990MHz), and the universal mobile telecommunication system (UMTS: 1920–2170MHz), have been developed and published in the open literature [1].

Planar antennas are also very attractive for applications in communication devices for wireless local area network (WLAN) systems in the 2.4GHz (2400–2484MHz) and 5.2GHz (5150–5350MHz) bands. In this section some of the works related to the mobile and WLAN applications have been referred and discussed.

Jin-Sen Chen et al. in the year 2014 presents “A triangular-ring slot antenna fed by coplanar waveguide”, feed line with protruded tuning stub and a back-patch at the bottom of the substrate for miniaturization and it is found that the resonant frequency can be significantly reduced as compared with coplanar wave guide fed conventional ring-slot antennas. A novel reactive impedance substrate for antenna miniaturization with enhanced bandwidth performance is presented by Mosallaei H et al. [1].

Hao Chun Tung et al. in the year 2012 proposed “a printed dual band monopole antenna for 2.4/5.2GHz WLAN access point”. The trident monopole antenna comprises a central arm for the 2.4 GHz band (2.4–2.484GHz) operation and two side arms for the 5.2 GHz band (5.15–5.35GHz) operation. [2].

“A multiband folded planar monopole antenna” has been proposed for mobile handset by Shun-Yun Lin in the year 2009 [3]. This paper introduces a folded planar monopole antenna, which has a very low profile of about one twentieth of the wavelength of the lowest operating frequency. The effect is achieved by using a bended rectangular radiating patch and an inverted L-shaped ground plane.

Hung Tien et al, 2013 present the “effect of slot loading on microstrip patch antennas” in [4]. The Koch island fractal and H-shape slots are introduced to microstrip patch antennas and their effect on reduction of the resonant frequency is determined. Additional slots of more complex geometry are implemented on the H-shaped patch to further bring down its resonance frequency.

Jen Yea Jan et al. in the year 2009 proposed “a microstrip fed dual band planar monopole antenna with shorted parasitic inverted L wire” for 2.4/5.2/5.8 WLAN bands. In this design inverted L shaped monopole is the exciting element and which controls the higher frequency. Another shorted inverted L shaped parasitic strip etched nearer to the monopole controls the lower frequency [5].

“A compact printed hook-shaped monopole antenna for 2.4/5-GHz WLAN applications” is presented by Chi-Hun Lee et al. in the year 2012 [6]. The proposed antenna is compact and the radiation patterns are nearly omni-directional in nature. Peng Sun et al. present a novel compact antenna operating at GSM, DCS, PCS and IMT2000 bands in [7]. A loosely coupled ground branch is used in the antenna, which covers all 2G and 3G wireless communication bands. A coplanar waveguide fed monopole antenna with dual folded strips for the radio frequency identification (RFID) application is presented by Wen-Chung Liu et al. [8] and the antenna has a very compact size including ground plane.

“A broad band U-slot rectangular patch antenna on a microwave substrate” is presented by Tong et al.2012 [9]. It is found that the crucial step to design a broad-band -slot patch antenna printed on a microwave substrate is to use a larger thickness than the case with a foam material. The foam material in the previous studies is replaced by a dielectric substrate of relative permittivity 2.33. This substitution can ease the fabrication of the antennas especially in an array environment. The computed resonant frequencies and far-field patterns agree well with measured data. The measured gain of each antenna is about 6.5dB.

“A broadband two-layer shorted patch antenna with low cross-polarization” is presented by Baligar 2011 [11]. The antenna has a bandwidth of 11% centered around 1.975GHz with a gain of 8.6dB, and exhibits better than -13dB cross-polarization levels in the H-plane. The computed and measured results of the co-planar configuration of the structure are compared with its new two-layer stacked configuration. The stacked geometry is found to reduce radiated cross-polarization levels significantly and offers a larger impedance bandwidth, a higher gain and radiation efficiency compared to the co-planar structure as well as the patch antenna structure.

“High directivity fractal boundary microstrip fractal boundary microstrip patch antenna” presented by Borja et al. October 2011[10] shows that a patch antenna with a fractal boundary exhibits localized modes. The localization effect produces an electric current density that is mainly concentrated in certain regions at the boundary. The result is that the microstrip fractal boundary antenna behaves as an array of antennas. When the localized modes are properly in phase, a broadside pattern is obtained and the directivity increases in comparison with the directivity of the antenna at the fundamental mode frequency.

“The combination of a microstrip patch antenna at 900 MHz and a folded reflector antenna in the 60GHz frequency range integrated in a common aperture” is described by Menzel et al. 2014[12]. The 900MHz antenna is based on a resonator-backed microstrip patch antenna, while the mm-wave antenna consists of a folded reflector antenna with a polarizing grid integrated into the antenna patch and a twisting and focusing planar reflector placed on the bottom of the 900 MHz antenna box. Both antennas show excellent performance.

“A Thin Internal GSM/DCS Patch Antenna for portable mobile terminal applications” is presented by K.L. Wong et al. in the year 2009 [13] The antenna incorporates a small portion of the top patch beyond the top edge of the system ground plane of the mobile terminal, which results enhanced bandwidths of the two resonant modes for covering the GSM and DCS bands. Kin Lu Wong et al. [14] present a shorted internal patch antenna which is mounted at the bottom end of the lower ground plane of the mobile phone, and can generate a wide operating band for UMTS operation.

“A novel Compact Wide-Band Planar Antenna for Mobile Handsets” is presented by Zhengwei Du et al. in the year 2011 [15]. It is capable of covering the major wireless communication and navigation systems bands like GSM, GPS, DCS, PCS, UMTS, and WLAN. The radiating patch is jointly designed with the shape of the ground plane to optimize its performance.

P. Ciais et al. in the year 2007 [16] present a "planar inverted-F antenna (PIFA) operates in penta-band suitable for handheld terminals". This antenna consists of capacitive loaded shorted patches, a slot, and an efficient antenna-chassis combination to achieve multiband and wideband performances to operate in the 850 MHz, 900 MHz, 1800 MHz, 1900 MHz, and UMTS bands. A wideband monopole antenna integrated within the front-end module package is proposed by Saou-Wen Su et al. [17]. The antenna is a good candidate for WLAN / WiMAX applications and is integrated within the frond-end module package of the system.

"A dual wide-band CPW-fed modified Koch fractal printed slot antenna", suitable for WLAN and WiMAX operations is proposed by Krishna et al. in the year 2008 [18] Here the operating frequency of a triangular slot antenna is lowered by the Koch iteration technique resulting in a compact antenna. Koch fractal slot antenna has an impedance bandwidth from 2.38-3.95GHz and 4.95–6.05GHz covering 2.4/5.2/5.8GHz WLAN bands and the 2.5/3.5/5.5 GHz WiMAX bands.

Paul L. Chin, Atef Z. Elsherbeni and Charles E. Smith present a "Characteristics of Coplanar Bow-Tie Patch Antennas" in the year 2007 [19]. This paper introduces a new concept of coplanar patch antenna, which consists of a bow-tie shaped patch surrounded by closely spaced ground conductor and a coplanar waveguide feed line. In this paper bandwidths of 484 MHz or 4.84% and 636 MHz or 6.36% for a -10 dB return loss level are achieved.

In literature review different microstrip and coplanar antennas are discussed which are published by different authors. It is concluded that lots of research is going on in field of microstrip and coplanar design.

This thesis presents coplanar waveguide - fed rectangular microstrip and coplanar patch antennas for C-band, S-band and X-band applications, which in turn, would be suitable for Bluetooth, WLAN and WiMAX operations. Rectangular patches are designed and simulated for 2.4 GHz, 3.5GHz, 6GHz, 7GHz and 10.5 GHz frequencies. HFSS Simulation results have shown that for same operating frequency and same substrate coplanar patch antennas give wider bandwidth and higher radiation efficiency than microstrip patch antenna. On the other side, the result has shown that microstrip patch antennas are more compact and possess high directivity than coplanar patch antennas.

Chapter 2

Theoretical Background

In the last few decades, planar antennas have been a field of interest for many researchers and scholars. With the revolution in electronic circuit miniaturization and large scale integration in the early 70's, demand for a compact antenna with small size, which can be integrated with MMIC design has increased. Planar antennas are substrate based antennas and they are easy for fabrication and integration with MMIC and PCB. These antennas have advantages such as low profile, light weight and ease of fabrication.

Planar patch antennas [20] are popular in wireless communication, because they have some advantages due to their conformal and simple planar structure. They allow all the advantages of printed -circuit technology. There are varieties of patch structures available but the rectangular, circular and triangular shapes [20] are most frequently used. Design of S-band (WIMAX), C-band (WLAN) antennas also got popularity with the advancement of planar patch antennas.

Moreover a large number of coplanar and micro strip patches to be used in wireless applications have been developed [21]. The rapid progress in wireless communications requires the development of lightweight, low profile, single feed antennas. Also it is highly desirable to integrate several RF modules for different frequencies into one piece of equipment. Hence, multiband antennas that can be used simultaneously in different standards have been in the focus points of many research projects [21]. Portable devices are widely used in our daily lives such as mobile phones, laptops with wireless connection.

The S-band is part of the microwave band of the electromagnetic spectrum. It is defined by an IEEE standard for radio waves with frequencies that range from 2 to 4 GHz, crossing the conventional boundary between UHF and SHF at 3.0 GHz. The S band is used by weather radar, and surface ship radar.

The C-band is a name given to certain portions of the electromagnetic spectrum, including wavelengths of microwave that are used for long distance telecommunications. C-band (4 to 8 GHz) and its slight variations contain frequency ranges that are used for, some Wi-Fi devices, some cordless telephones, and some weather radar systems.

The main goal of this work is to design a rectangular coplanar and micro strip patch antennas which will be applicable for X band, C band and S band applications and do a performance comparison between these two planar patch antennas and put the most suitable antenna forward for Microwave application systems.

2.1.Microstrip patch antenna

A class of antennas that has gained considerable popularity in recent years is the microstrip antenna. A typical microstrip element is illustrated in Fig. 2-1. There are many different types of microstrip antennas, but their common feature is that they consist of four parts:

- ✓ very thin flat metallic region often called the patch;
- ✓ Dielectric substrate;
- ✓ Ground plane, which is usually much larger than the patch; and
- ✓ Feed, which supplies the element RF power.

Microstrip elements are often constructed by etching the patch (and sometimes the feeding circuitry) from a single printed-circuit board clad with conductor on both of its sides.

In its simplest form, a microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate, and a ground plane on the other side [22].

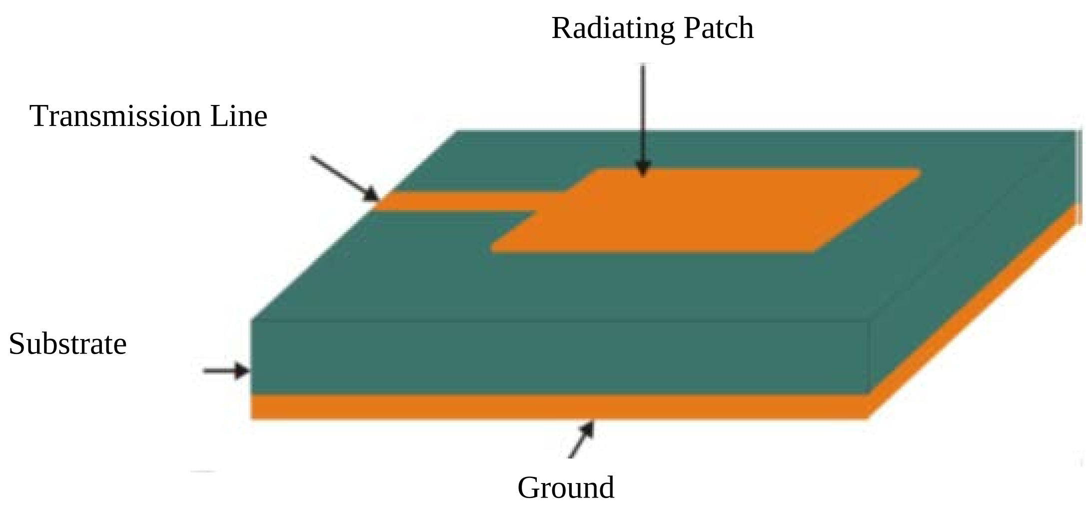

Figure.2.1 The basic geometry of microstrip radiator [22]

2.1.1. Method of microstrip antenna analysis

The importance of microstrip radiators was realized when researchers noted that almost half of the power in a microstrip radiator escapes as radiation. Thus, a microstrip radiating patch with considerable radiation loss was defined as microstrip antennas. Later, it was proved that this radiation mechanism was arising from the discontinuities at each end of the microstrip transmission line [23]. The basic form of a patch antenna consists of a flat plate over a dielectric substrate that at the same time is over a ground plane. The metal patch is normally made from copper foil but the substrate material can vary between different types, depending on which it is needed. The three layers are the minimum elements to define a patch antenna as depicted in Fig 2.1.

The radiating patch can be designed with a variety of shapes such as: square, circular, triangular, semicircular, sectorial, and annular ring shapes; but rectangular and circular configurations are the most commonly used configuration because of ease of analysis and fabrication.

There are several methods of analysis for analyzing the patch antenna and most of them consider the 2D planar element. The three most common methods of analysis are transmission line model, cavity model and full wave model. The transmission line model is the simplest model and gives a good physical insight, but it is not very accurate. The cavity model gives good accuracy and physical insight, but it is more complex. And finally, the full wave model is by far the most accurate and versatile model, offers more options, but it gives less physical insight and is much more complex to use than the other two models.

2.1.1.1. Transmission Line Model

The transmission line model considers the rectangular patch antenna to be parallel plate transmission line connecting to radiating slots each of width W and height h as shown by Fig 2.2.

When the patch is excited by a feed line, charge is distributed on the underside of the patch and the ground plane. At a particular instant of time the attractive forces between the underside of the patch and the ground plane tend to hold a large amount of charge. Moreover, the repulsive forces push the charges to the edge of the patch, creating a large density of charge at the edges. These are the sources of fringing field as shown in Fig 2.2. Radiation from the microstrip antenna can occur from the fringing fields between the periphery of the patch and the ground plane.

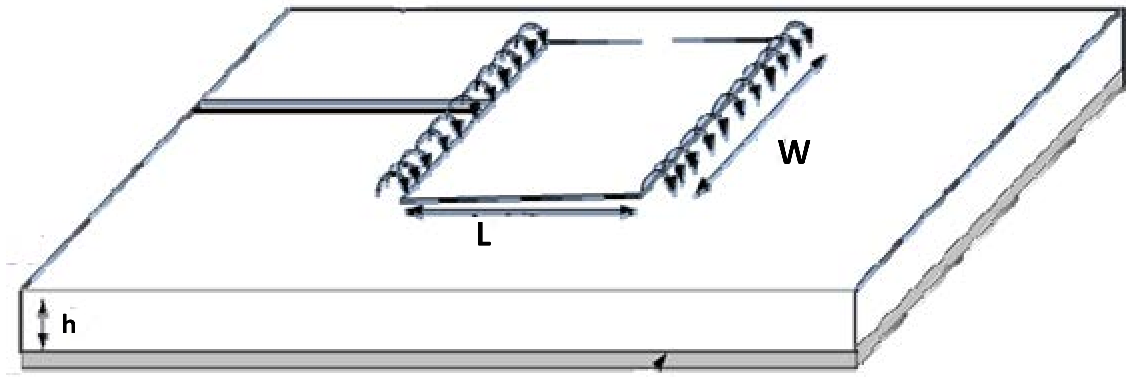

Figure 2.2 Fringing Fields [16]

Transmission line model is not accurate and lacks versatility but it is the easiest one and gives physical insight and field distribution of the antenna. Microstrip patch antenna has a length L, width W and thickness h (substrate). To obtain TM_{10} mode, the length of the patch should be less than $\lambda/2$. The wavelength is calculated considering the dielectric constant ε, and the length of patch is [16].

$$L = \frac{\lambda_{eff}}{2} = \frac{\lambda_{freespace}}{\sqrt{\varepsilon_r}} \qquad \text{.......................................(2.1)}$$

The Voltage, Current and impedance distributions, as a function of patch length, are shown in Fig 2.3. The voltage has maximum and minimum values at the edge on each side of length and zero value in the middle due to the fact that the edges appear as open circuits. By contrast, the current intensity has zero value at edges and maximum value in the middle. Thus it can be seen that there is no field variation along width W. Since the fields are in contra-phase at edges it causes the normal components of the field to cancel each other in the broadside direction. However, the tangential components are in phase and cause radiation normal to the patch surface.

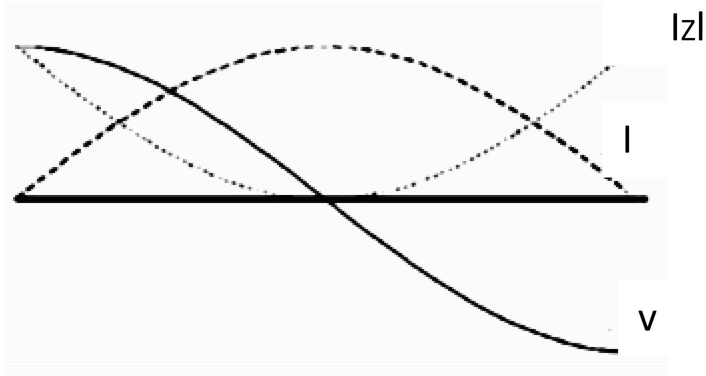

Figure 2.3: V, I and IzI distribution along the patch length [16]

The slots of the patch give very high impedance terminations at the end of the transmission line, thus the structure is expected to be highly resonant which is dependent on the length of the patch. The resonant length of the patch antenna is therefore not equal to physical length but is slightly more than the length L due to the fringing effects as shown in Fig 2.4. Leff of the patch is greater than the length L of the patch due to fringing fields. In fact, the effective length Leff is given by [20].

$$L = L_{eff} - 2\Delta L \quad \text{.......(2.2)}$$

Where,

$$\Delta L = 0.412h \frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad \text{.......(2.3)}$$

There is no radiation along the length L of the patch, so they are called non-radiating edges. Since the width W of the patch is responsible for radiation thus the value of the width can help antenna to radiate more efficiently. Its value is [20]

$$W = \frac{C}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}} \quad \text{.......(2.4)}$$

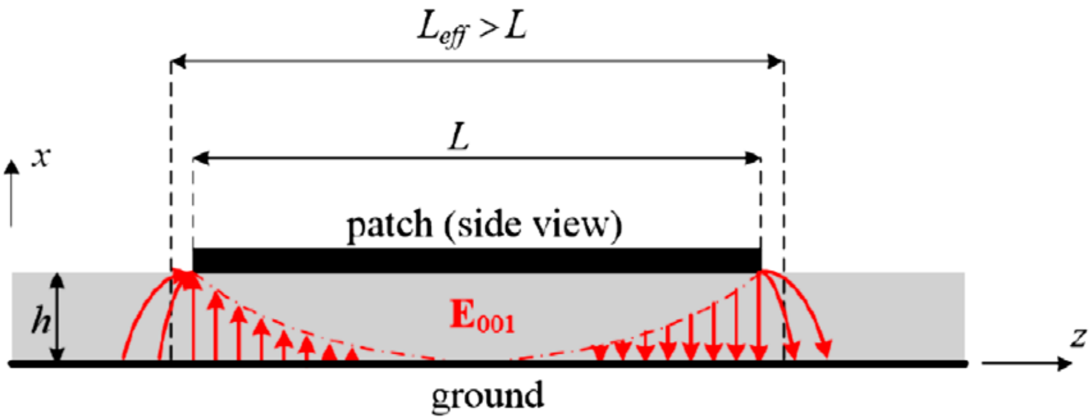

Figure 2.4: Fringing fields [20]

2.1.1.2. Cavity Model

The cavity model in analyzing the microstrip antennas is based on the assumption that the region between the microstrip patch and ground plane is a resonance cavity bounded by ceiling and floor of electric conductors and magnetic walls along the edge of the conductor as shown in Fig 2.5 [21].

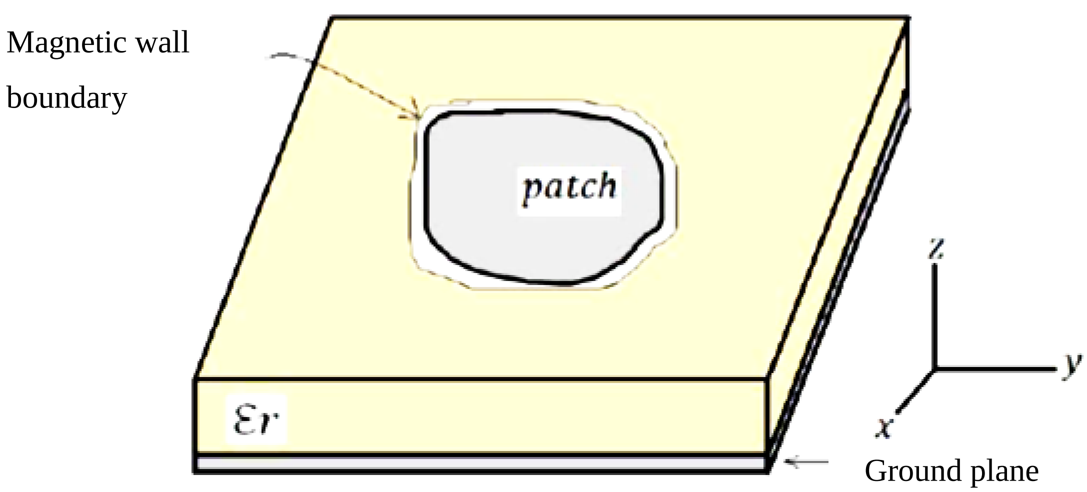

Figure 2.5 Magnetic wall model of a microstrip patch antenna [21]

The assumption above is based on the observation of:

1. There are only three field components in the region enclosed by the cavity: E component in the z axis (Ez) and two components of H along the x and y axis (H_x, H_y)
2. Because h (height of the substrate) is very thin (h<<λ), field in the interior region do not vary with z-coordinates for all frequencies.
3. The electric current in the microstrip patch has no component normal to the edge of the patch at any point.

This model is fair good in studying the microstrip resonators with the edge extending slightly to account for the fringing field.

Consider the microstrip antenna in the figure (2.6) [20].

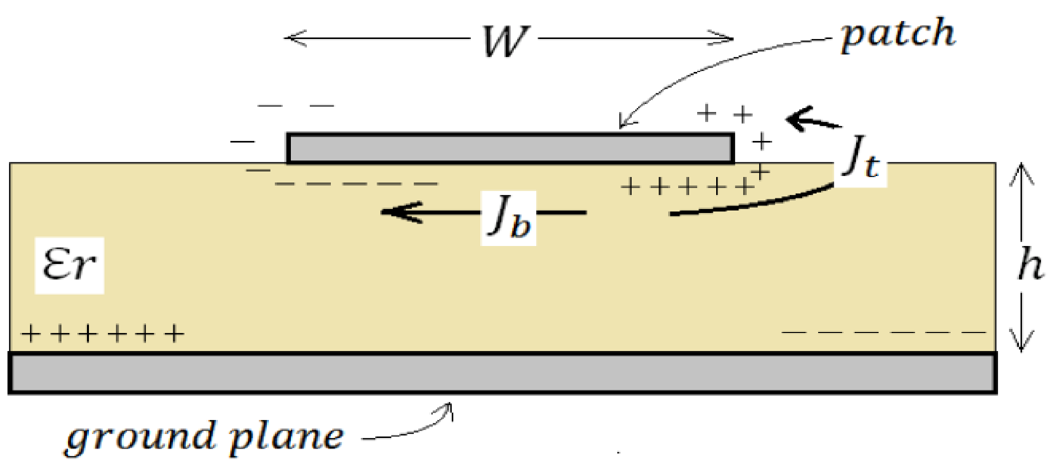

Figure 2.6 Charge distribution and current density on a microstrip antenna [20]

When the microstrip antenna is connected to a microwave source, the charge distribution will be established on the upper and the lower planes of the antenna as shown in Figure (2.6). The charge distribution is controlled by two mechanisms; attractive and repulsive. The attractive force is between the opposite charges on the patch and on the ground plane, it creates a current density inside the dielectric J_b at the bottom of the patch.

The repulsive force is between the like charges tends to push the charges from the bottom of the patch around the edge of the patch to the top of the patch, this will create the current density J_t as shown in Figure (2.6).

In the case of microstrip antennas W>>h the attractive mechanism dominates and charges concentration will be within the dielectric, under the patch. And the current flow around the edge can be neglected because it decreases as the ratio height to width decreases. This would allow the four side walls to be modeled as perfect magnetic conducting surfaces which ideally would not disturb the magnetic field and the electric field distribution beneath the patch. This good approximation to the cavity model leads us to deal with the side walls as perfect magnetic conducting walls.

We have mentioned before that the field inside the cavity has three field components E_z,H_x and H_y ; the wave equation (2.5) can be re-written as equation (2.6):

$$\nabla \times \nabla \times \vec{E} - K^2\vec{E} = -j\omega\mu_o\vec{J} \quad \text{.............................. (2.5)}$$

$$\nabla^2 E_z + k^2 E_z = j\omega\mu_o\, \hat{z}.\vec{J} \quad \text{..(2.6)}$$

Where, $k^2 = \omega^2\mu_o \epsilon_r \epsilon_o$, and it is the wave number.

$\vec{J} =$ Electric current density fed by the feed line to the patch.

$\hat{z} =$ unit vector normal to the plane of the patch.

In addition on the top and the bottom conductors:

$$\hat{n} X \vec{E} = 0$$

And on the walls:

$$\hat{n} X \vec{H} = 0$$

2.1.1.3. Full Wave Solutions-Method of Moments

One of the methods, that provide the full wave analysis for the microstrip patch antenna, is the Method of Moments. In this method, the surface currents are used to model the microstrip patch and the volume polarization currents are used to model the fields in the dielectric slab. It as been shown by Newman and Tulyathan how an integral equation is obtained for these unknown currents and using the Method of Moments, these electric field integral equations are converted into matrix equations which can then be solved by various techniques of algebra to provide the result. A brief overview of the method of moments is given below [20].

The basic form of the equation to be solved by the method of moments is:

$$F(g) = h \quad \text{...} \quad (2.7)$$

Where F is a known linear operator, g is an unknown function, and h is the source or excitation function. The aim here is to find g, when F and h are known. The unknown function g can be expanded as a linear combination of N terms to give:

$$g = \sum_{n=1}^{N} a_n g_n = a_1 g_1 + a_2 g_2 + \ldots\ldots\ldots\ldots\ldots.. + a_N g_N \quad \text{.............} (2.8)$$

Where a_n is an unknown constant and g_n is a known function usually called a basis or expansion function. Substituting equation (2.7) in (2.8) and using the linearity property of the operator F, we can write:

$$\sum_{n=1}^{N} a_n F(g_n) = h \quad \text{...} \quad (2.9)$$

The basic functions g_n must be selected in such a way, that each $F(g_n)$ in the above equation can be calculated. The unknown constants a_n cannot be determined directly because there are N unknowns, but only one equation. One method of finding these constants is the method of weighted residuals. In this method, a set of trial solutions is established with one or more variable parameters. The residuals are a measure of the difference between the trial solution and the true solution. The variable parameters are selected in a way which guarantees a best fit of the trial functions based on the minimization of the residuals. From the antenna theory point of view, we can write the Electric field integral equation as

$$E = f_e\ (J) \quad \text{...} \ (2.10)$$

Where, E is the known incident electric field

J is the unknown induced current.

f_e is the linear operator.

The first step in the moment method solution process would be to expand J as a finite sum of basis function given as:

$$J = \sum_{n=1}^{N} J_i \mathrm{b}_i \text{..} \ (2.11)$$

Where, b_i is the basis function and J_i is an unknown coefficient. The second step involves the defining of a set of M linearly independent weighting functions. Where, J is the current vector containing the unknown quantities. The vector E contains the known incident field quantities and the terms of the Z matrix are functions of geometry. The unknown coefficients of the induced current are the terms of the J vector. Using any of the algebraic schemes mentioned earlier, these equations can be solved to give the current and then the other parameters such as the scattered electric and magnetic fields can be calculated directly from the induced currents.

2.1.2. Advantages and Disadvantages of microstrip antennas

The micro strip antenna has proved to be an excellent radiator for many applications because of its several advantages, but it also has some disadvantages; however some of them can be overcome using new techniques of feeding, configuration of the patch, etc.

Advantages

- They are light in weight and take up little volume because of their low profile. They can be made conformal to the host surface.
- Low fabrication cost, hence can be manufactured in large quantities.
- They are easier to integrate with other micro strip circuits on the same substrate.
- They support both, linear as well as circular polarization.
- They can be made compact for use in personal mobile communication and hand held devices.
- They allow multiple-frequency operation, because one can use stacked patches.
- Mechanically robust when mounted on rigid surfaces.

Disadvantages

- Narrow bandwidth.
- Lower power gain.
- Lower power handling capability.
- Polarization impurity.
- Surface wave excitation.
- Extraneous radiation from feeds and junctions.
- Poor end fire radiator except tapered slot antennas

2.1.3. Applications of Microstrip Patch Antenna

The microstrip patch antennas are well known for their performance and their robust design, fabrication and their extent usage. They can be applied in various fields such as medical applications, satellites and military systems like in the rockets, aircrafts missiles etc. The usages of the microstrip antennas are spreading widely in all the fields and areas and now they are booming in the commercial aspects due to their low cost of the substrate material and the fabrication. It is also expected that due to the increasing usage of the patch antennas in the wide range this could take over the usage of the conventional antennas for the maximum applications.

Some of the applications for the microstrip Patch Antenna are in the following [16]

- Radio altimeters
- Command and control system
- Remote sensing and environmental instrumentation
- Feed element in complex antennas
- Satellite navigation receivers
- Mobile radio
- Integrated antennas
- Doppler and other radars
- Satellite communication and direct broadcast services (DBS)

2.2. The Coplanar Waveguide

Coplanar waveguide is an alternative to microstrip line. The coplanar waveguide has been invented by Cheng P. Wen in 1969 while he was working in Sarnoff Laboratories [27]. “A Coplanar waveguide consists of a strip of thin metallic film on the surface of a dielectric slab with two ground electrodes running adjacent and parallel to the strip” [28]. A CPW layout is shown in Fig 2.7.

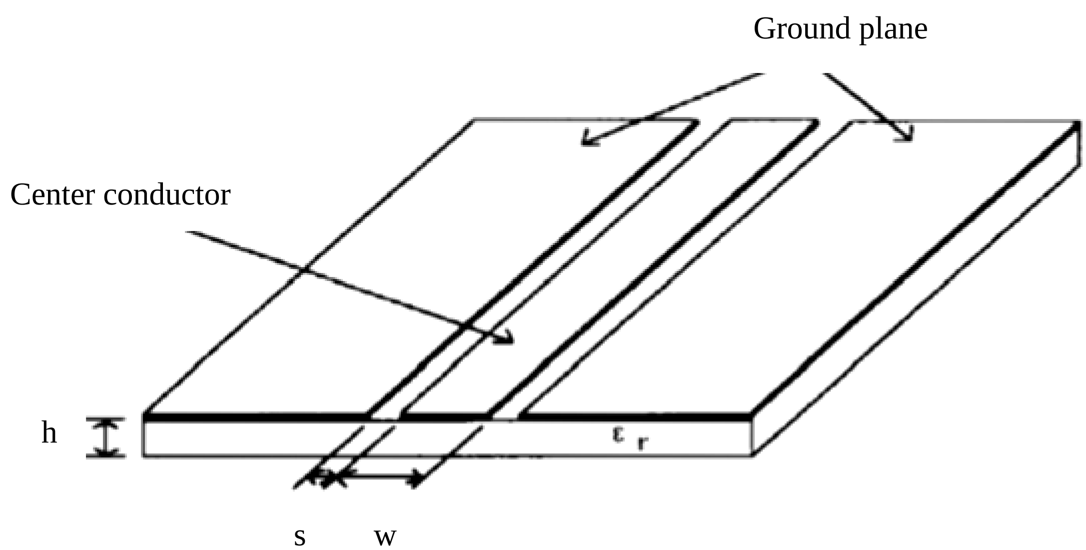

Figure 2.7: Coplanar Waveguide feed [28]

Coplanar waveguide is a transmission line system consisting of a central current-carrying trace on the top of a substrate, coplanar with side grounds extending beyond a symmetric gap to either side of trace. A coplanar waveguide is the preferred transmission line for microwave monolithic integrated circuits. Both coplanar waveguide and microstrip antennas belong to the planar geometry. Therefore, for integrating microstrip antennas with coplanar waveguide, it is desirable to feed the microstrip and coplanar patch antenna with a coplanar waveguide. The coplanar waveguide fed antenna have been widely used for wireless communications owing to their many attractive features such as wide bandwidth, simplest structure of a single metallic layer, no soldering points, and easy integration with MMICs etc. [28].

Following are the few features of CPW [27]:

- The dimensions of the center strip, the gap, the thickness and permittivity of the dielectric substrate determines the effective dielectric constant, characteristic impedance and the attenuation of the line.
- The gap in the coplanar waveguide is usually very small and supports electric fields primarily concentrated in the dielectric. With little fringing field in the air space, the coplanar waveguide exhibits low dispersion. In order to concentrate the fields in the substrate area and to minimize radiation, the dielectric substrate thickness is usually set equal to about twice the gap width.
- Has a zero cut-off frequency (suitable for wideband), but its low order propagation mode is indicated with Quasi-TEM because it is not a real TEM mode. At higher frequencies, the field becomes less-TEM, and more TE in nature. The magnetic field is elliptically polarized. The E and H field distribution in coplanar waveguide feed is shown in Fig 2.8.
- It is a printed circuit analog of the three-wire transmission lines.
- It has two ground planes, which must be maintained at the same potential to prevent unwanted modes from propagating. If the grounds are at different potentials, the coplanar waveguide mode will become uneven, with a higher field in one gap than the other.
- In the coplanar waveguide, the effective dielectric constant is approximately independent of geometry, and simply equal to the average of dielectric constants of air and the dielectric substrate.
- Frequency dispersion for coplanar waveguide is generally small, but there is a mild dependence on line dimensions, and narrow lines are less frequency dispersive than wide lines.

In coplanar waveguide, a ground plane exists between any two adjacent lines; hence, cross talk effects between adjacent lines are very week. As a result, circuits can be made denser than conventional Microstrip circuits.

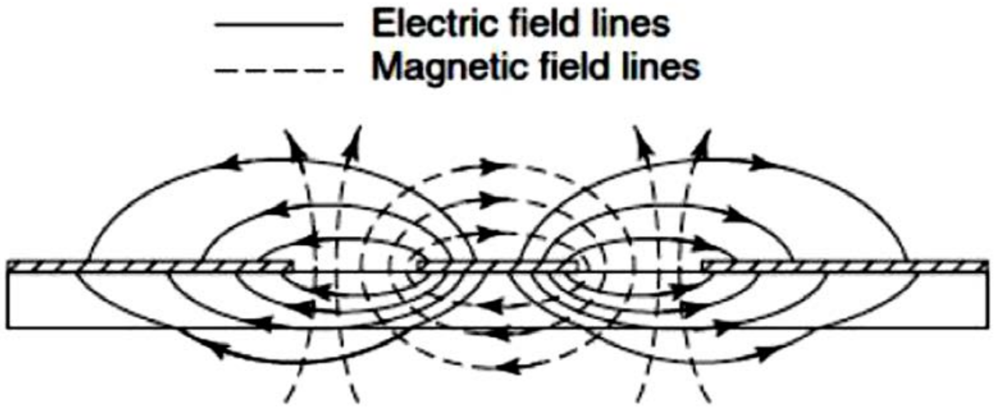

Figure 2.8: Electric-E and Magnetic-H felid distribution across CPW [27]

2.2.1. Advantages and Disadvantages of CPW

The following are advantages and disadvantages of coplanar waveguide

Advantages

- It gives huge circuit isolation because of the RF grounds in the traces. Many High-resolution RF switches use grounded coplanar waveguide to get 60 dB of isolation.
- Bottom reference plane of the grounded coplanar waveguide provides structural strength.
- It gives lower conductor losses and dispersion.
- Since there is no connecting via, so coplanar waveguide has low radiation losses at the discontinuities.
- Lower crosstalk improves MMIC layout density from 30% to 50% compared to microstrip.

- It provides 30% cost reduction in MMIC´s fabrication because of simpler processing steps and elimination of backside processing.
- Also the impedance of the coplanar waveguide transmission lines is lower than the usual microstrip lines which allow the ease in the impedance matching of the circuit.

Disadvantages

- It side strips generate both odd and even modes current that can cause serious mode coupling.
- It has lower thermal dissipation and lower structural strength.
- High frequency losses due to over modes are more pronounced on coplanar waveguide than microstrip.
- In general, coplanar waveguide experience higher losses compared to microstrip.

2.3. Coplanar patch antenna

An initial design for the coplanar rectangular patch antenna will be obtained by choosing the length of the non-radiating edges to be $\lambda_g/2$ at the operating frequency, where λ_g is the guided wavelength. The coplanar rectangular patch antenna is then fed with a coplanar waveguide. The resonance frequencies could be adjusted by modifying the length of the coplanar rectangular patch antenna. Impedance matching could be realized by adjusting the width of the coplanar rectangular patch antenna. Therefore, the bandwidth could be adjusted by modifying the width of the coplanar rectangular patch antenna.

The rectangular coplanar patch antenna is placed centrally about the end edge of coplanar waveguide feed line. The electric field distributions along the top and bottom slots of the coplanar patch antenna are in-phase and hence these slots were referred to as radiating edges (RE). The electric field distributions in right and left slots of the coplanar patch antenna were out of phase and hence these slots were referred to as non-radiating edges (NRE) [29]

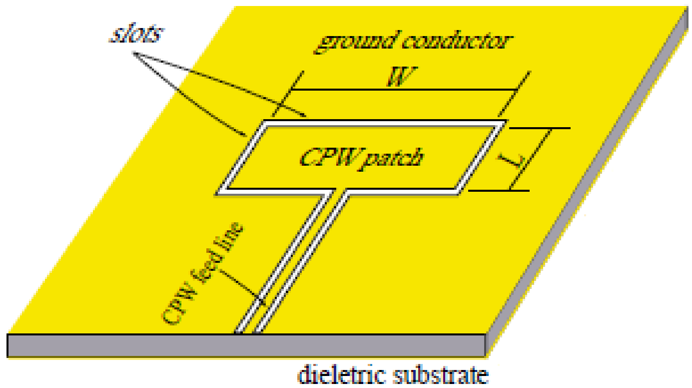

Figure 2.9: Schematic Diagram of coplanar fed coplanar patch antenna [29]

The inset feed design equation for a microstrip patch antenna is applicable to coplanar patch antenna. The inset helps in matching the 50 Ω feed line to a particular point in the patch where the impedance is close to 50Ω.

Coplanar patch antennas have coplanar waveguide input terminals that can directly be connected to the coplanar waveguide terminals of millimeter-wave (photonic devices), and reduce the insertion loss between connections [29].

Advantages of Coplanar Patch Antenna

- Low radiation loss
- Less dispersion
- Uni-planar configuration

2.4. Feeding techniques of planar antennas

The feeding method or excitation technique is an important design parameter because it influences the input impedance, the polarization characteristic and the antenna efficiency. As the feeding method influences the input impedance, it is often used for purposes of impedance matching.

Planar antennas can be excited or fed directly or indirectly. A microstrip antenna is fed directly using a connecting element such as the use of a coaxial probe or by a microstrip line, when it is excited indirectly, there is no direct metallic contact between the feed line and radiating patch, and this could be using proximity coupling or by aperture coupling [24]

2.4.1. Coaxial or probe feed

In case of feeding the patch antenna with coaxial or probe feed, the center conductor coaxial connector extends through the substrate and then is soldered to the radiating patch, while the outer conductor is connected to the ground plane. The coaxial feed is shown in the Fig 2.10.

Advantage: The feed can be placed at any point on the patch, which allows achieving the perfect matching with the input impedance of the patch.

Disadvantage: Geometry does not remain completely planar because a hole has to be drilled in to the substrate so that the inner conductor of the coaxial can be soldered to the patch. Also the configuration becomes asymmetrical because of this feeding option [24].

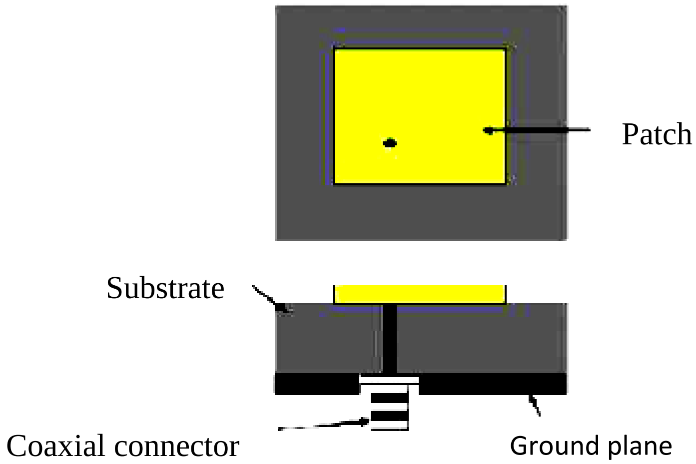

Figure 2.10: Coaxial Cable fed [24]

2.4.2. Microstrip Line Feed

The microstrip patch can be fed with a microstrip line where the strip line connects the patch at the edge. So the impedance of the line should be matched to the edge impedance of the patch. There are several techniques to achieve the impedance patching which are inset feed, non-radiating edge feed and use of quarter wave transformers as shown in Fig 2.11(a) (b) (c) and (d) respectively.

Advantage*:* This feed provides a planar structure so they are easy to fabricate.

Disadvantage: There are radiations from the feed especially in case of millimeter-wave range where the width of the feed line becomes comparable to the size of the patch.

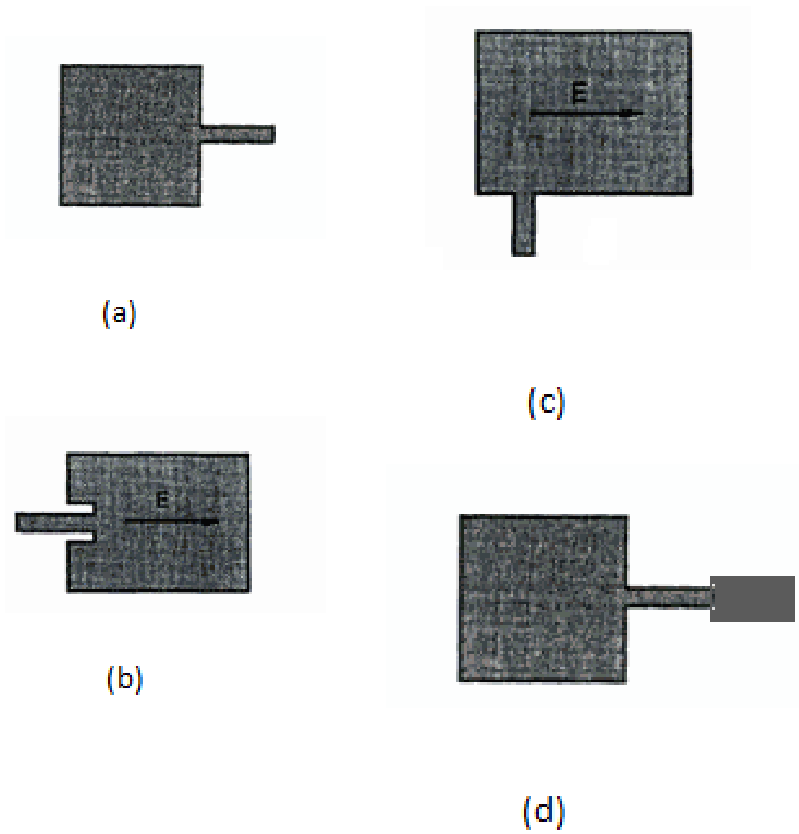

Fig 2.11: (a) Microstrip line feed (b) Inset Feed (c) Microstrip line feed at non-radiating edge (d) Microstrip line feed with quarter wave transformer [24]

2.4.3. Aperture coupling

In this type of feeding technique, the radiating patch and the microstrip feed line are separated by the ground plane. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane. The coupling aperture is usually centered under the patch, leading to lower cross polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. A more cleared sketch of aperture coupled microstrip patch is shown in Fig 2.12. The feed line is along the resonant dimension of the patch. The slot, therefore, has its length perpendicular to the resonant dimension. [25].

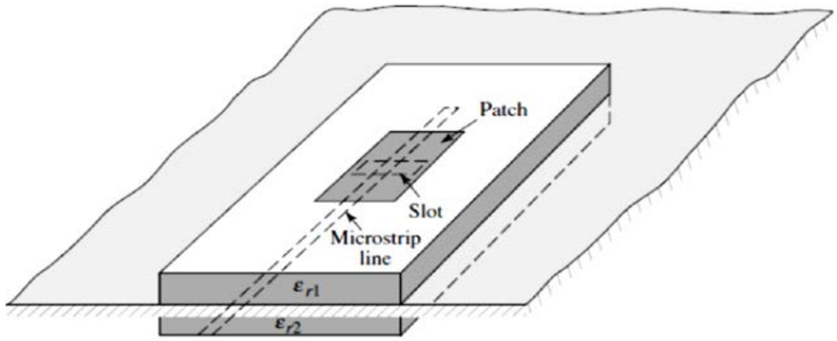

Figure 2.12 Aperture-coupled feed [25]

2.4.4. Inset feed patch antenna

The basic rectangular patch antenna, for both microstrip and coplanar, has a high input impedance. In order to improve the efficiency and to get a perfect match feed when the elements are going to be loaded to it, an inset feed method is used. The basic characteristic is to reduce this impedance to 50 Ω with the structure shown in the Fig 2.13. Inset feeding gives good impedance matching without the need for additional matching networks [26].

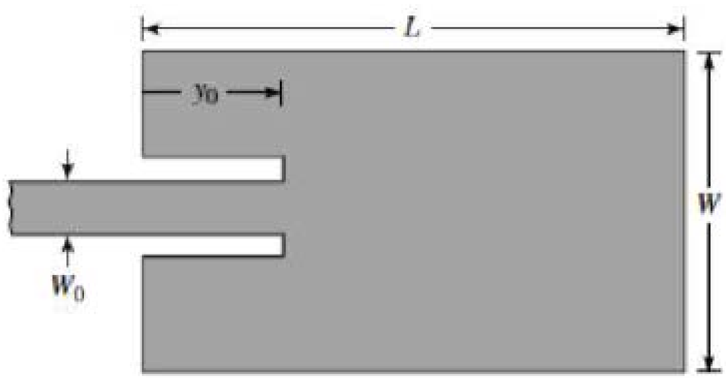

Figure 2.13: Inset feed patch antenna [26]

Rectangular microstrip and coplanar patch antenna fed by coplanar waveguide feed at the edge (y_o= 0)(referring the above figure) will have higher input resistance varying approximately from 150Ω to 450Ω .

The input impedance falls rapidly as the inset position moves toward the center from the edge. The following formula is used to calculate the inset length to achieve 50Ω input impedance for the commonly used thin dielectric substrate. This formula is applicable for both microstrip and coplanar patch antennas [30]

$$y_o = 10^{-4}[0.001699\epsilon r^7+0.13761\epsilon r^6-6.1783\epsilon r^5+93.187\epsilon r^4-682.69\epsilon r^3+2561.9\epsilon r^2-4043\,\epsilon r+6697]\frac{L}{2} \quad (2\leq \epsilon r\leq 10) \quad \ldots\ldots\ldots\ldots\ldots\ldots(2.12)$$

Impedance matching in a patch antenna is an important issue. Generally a 50Ω transmission line is considered as a feed line, because 50Ω transmission line has a very low reflection coefficient. However, impedance at the edge of the patch is generally more than 300Ω, which requires some additional impedance matching techniques. Now to couple maximum power from the feed to patch we can introduce a λ/4 impedance transformer line between patch and the feed line. In case of direct feeding, the feed line is shifted on either side of the patch along the edge until an impedance of 50Ω is achieved.

One more technique used to match the impedance of the patch with respect to feed line is to design an inset fed patch antenna. In general, the impedance in a patch decreases from the edge to the center of the patch. At the center of the patch impedance is zero.

2.4.5. Coplanar waveguide Feed

As attributed from its name, patch radiator and ground plane share the same plane above the dielectric substrate, opposed to usual convention of microstrip antennas in which patch surface and ground plane are separated by dielectric substrate. The characteristic impedance and the attenuation of the feed line are resolute by the dimensions of the center strip and the gap as well as the dielectric substrate thickness and permittivity. This basic arrangement is known as conventional coplanar waveguide [27]. Figure 2.14 shows the elementary coplanar waveguide fed structure.

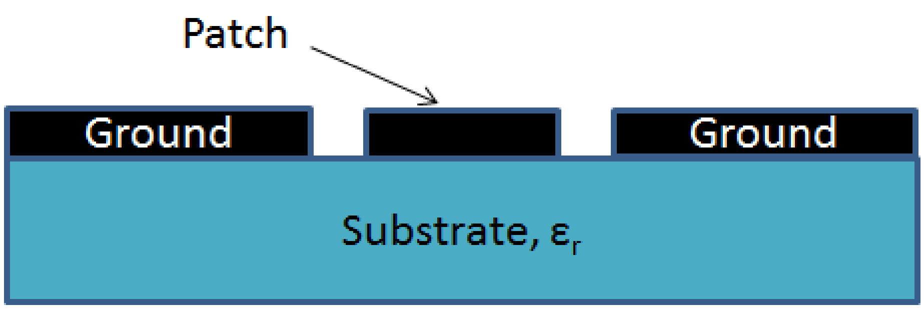

Figure 2.14: Inset feed patch antenna [27]

2.5. Antenna Parameters

2.5.1. Efficiency and Quality Factor

For a microstrip patch antenna, efficiency can be defined as the power radiated from the microstrip element divided by the power received by the input to the element. Factors that affect the efficiency of the antenna and make it high or low are the dielectric loss, the conductor loss, the reflected power (Voltage Standing Wave Ratio), the cross polarized loss, and power dissipated in any loads in the element.

$$e = \frac{\text{Prad}}{\text{Prec}} \ldots\ldots\ldots\ldots\ldots..(2.13)$$

Where,

Prad =Power radiated by the antenna

Prec =power fed to the antenna

Radiated efficiency is a measure of the power radiated through the antenna as an electromagnetic wave to the power fed to the antenna terminals. If an antenna could be made to be a totally ideal electrical component, it would transform all of the power fed to its terminals to a radiating electromagnetic energy that propagates into the surrounding space. This is possible only in theory, and thus in real life some of the power fed to the antenna terminals is always lost. For example, the mismatch between the antenna element and the feeding network causes power losses.

Antenna efficiency is a useful and informative measure of antenna “economic efficiency.” With a quick glance, the antenna’s capability to use the power fed to the connection pads can be evaluated and the amount of power required from the radio module can be determined in order to achieve a certain performance level. Antenna efficiency does not consider radiation direction and thus is a useful performance metric for measuring the efficiency of mobile devices, which have an omni-directional radiation pattern. In mobile devices, no specific direction of radiation is emphasized. On the other hand, if the antenna is supposed to radiate in a specific direction, (i.e. the antenna is designed to have some directive characteristics in its radiation pattern) then antenna gain is a better performance metric.

2.5.2. Return Loss

Return loss is an important parameter when testing an antenna. It is related to impedance matching and the maximum power transfer theory. It is also a measure of the effectiveness of an antenna to deliver power from source to antenna. The return loss (RL) is defined by the ratio of the incident power of the antenna to the power reflected back from the antenna of the source; the mathematical expression is:

$$RL = 10\log_{10}\frac{Pin}{Pref} \text{ (dB)}\ldots\ldots\ldots\ldots\ldots\ldots(2.14)$$

Another definition of return loss, from equation (2.9), is the difference in dB between the power sent towards the antenna and the power reflected from it. It is always positive when the antenna is passive and negative when it is active. We can express equation (2.9) in terms of voltage-standing-wave-ratio and impedance as follows [18]:

$$RL = 10\log_{10}\left|\frac{1}{\rho}\right| \text{ (dB)}$$

$$= -20\log_{10}|\rho| \text{ (dB)} \qquad \ldots\ldots\ldots\ldots(2.15)$$

$$\text{RL} = 20\log_{10}\left|\frac{VSWR+1}{VSWR-1}\right| \text{ (dB)} \qquad \ldots\ldots\ldots\ldots(2.16)$$

$$\text{RL} = 20\log_{10}\left|\frac{Z1+Z2}{Z1-Z2}\right| \text{ (dB)} \qquad \ldots\ldots\ldots\ldots(2.17)$$

Where,

ρ is the complex reflection coefficient at the input of the antenna.

VSWR is the voltage standing wave ratio.

Z1 and Z2 and are the impedance of the source and the antenna respectively

2.5.3. Antenna Bandwidth

The antenna bandwidth is defined as the "range of frequencies with in which the antenna conforms to the specific standard with respect to some characteristics" [19]. The antenna characteristics that are used to determine the bandwidth can be input impedance, radiation pattern, Beam width, polarization, side lobe level or gain. The bandwidth of a broadband antenna can be defined as the ratio of the upper to lower frequencies of acceptable operation.

$$BW_{broadband} = \frac{f_H}{f_L} \quad \ldots\ldots\ \ldots\ldots\ldots\ \ldots\ldots\ldots\ (2.18)$$

The bandwidth of a narrowband antenna can be defined as the percentage of the frequency difference over the center frequency.

$$BWbroadband\ (\%) = \frac{[f_H - f_L]}{f_L} * 100 \quad \ldots\ldots\ldots\ldots(2.19)$$

f_H = upper frequency , f_L= lower frequency f_C= center frequency

2.5.4. Radiation Pattern

The radiation pattern of an antenna is the plot of the far field radiation as a function of spatial coordinates which are elevation angle θ and azimuthal angle φ. It is basically the plot of the radiated power of antenna. An isotropic antenna is the one that radiates equally in all directions. An isotropic antenna is not possible to realize in practice and is useful only for comparison purposes. A more practical type is the directional antenna which radiates more power in some directions and less power in other directions.

Chapter 3

Antenna Design

In this chapter the coplanar waveguide fed rectangular coplanar and microstrip patch antennas are designed at their respective resonant frequency. The center frequencies selected are; 2.4GHz, 3.5GHz, 6GHz, 7GHz, and 10.5 GHz. The design is based on transmission line model analysis. In the design process there are three essential parameters that are taken in to consideration: the frequency of operation f, the dielectric constant of the substrate and the height of the dielectric substrate h.

In the designing of these antennas three basic parameters are required to be decided, such as thickness of substrate, relative permittivity and geometry of the patch. The first step is to select the appropriate substrate and thickness of substrate. Bandwidth and radiation efficiency increase with substrate thickness. Radiation efficiency of the planar patch antenna mainly depends on the dielectric constant or permittivity of the substrate, because permittivity of a substrate affects transmission efficiency [8]. And therefore, low dielectric constant is selected as the antenna gives better efficiency, low losses and higher bandwidth. Thick substrates having low dielectric constant and low dissipation factor give higher efficiency, larger bandwidth, and loosely bound fields for radiation [8]. But, they also have the disadvantage of arriving at large dimensions for the antenna.

Rectangular and square patches are the first and probably the most utilized patch conductor geometries. Rectangular patches tend to have the largest impedance bandwidth, simply because they are larger than the other shapes. Square patches can be used to generate circular polarization [8]. In this thesis, the rectangular patch has been selected for the antenna, concerning on the mentioned advantage.

Thus, in this thesis, the substrate that was used in the design process for both Coplanar and Microstrip patch antenna is FR4 Epoxy Glass, which has relative permittivity of 4.4 and substrate height 1.6mm, which in turn fulfill the requirement for low permittivity and high substrate height.

3.1 Design of CPW fed microstrip antenna for S, C and X band Application using rectangular patch

Practical values can be calculated by using standard formulas.

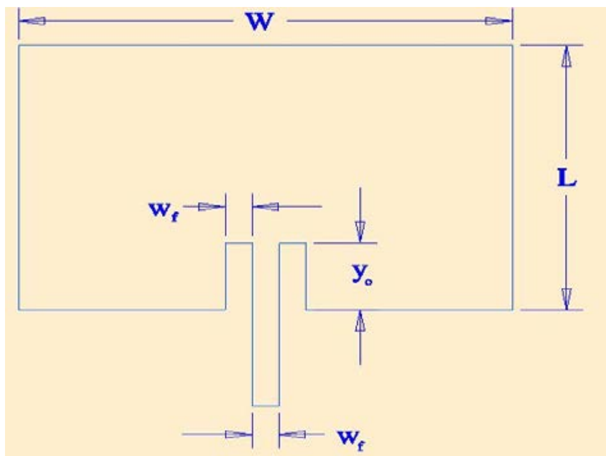

Figure 3.1 Typical inset fed microstrip patch antenna.

Step 1: Calculation of the width (W)

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

Here c $=3x10^{11}$ mm/s

Where, c = speed of light

ε_r = relative permittivity

W = width of patch

Step 2: Calculation of the Effective Dielectric Constant. This is based on height, dielectric constant of the dielectric and the calculated width of the patch antenna.

$$\varepsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \text{ ……………………… (3.2)}$$

Where ε_{reff}=effective permittivity

ε_r= relative permittivity

h = substrate thickness

W = width of patch

Step 3: Calculation of the Effective length

$$\text{Leff} = \frac{c}{2fo\sqrt{\varepsilon_{reff}}} \text{……………………………………… (3.3)}$$

Where, Leff = effective length

Step 4: Calculation of the length extension ΔL

$$\Delta L = 0.412h\,\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \text{…………………………(3.4)}$$

Where, ΔL is the length extension because of fringing field.

Step 5: Calculation of actual length of the patch

$$L = L_{eff} - 2\Delta L \quad \text{…………………………………….. (3.5)}$$

Where, L_{eff}= effective length

L = length of patch

Step 6: Calculation of the ground plane dimensions:

The transmission line model even though is applicable to infinite ground planes only but for practical considerations, a finite ground plane is used. However, size of ground plane should be greater than the patch dimensions by approximately six times the substrate thickness all around the periphery so that results are similar to the one using infinite ground plane. The ground plane dimensions are calculated as:

Lg= 6h+L …………………………………... (3.5)
Wg= 6h+W………………………………. … (3.7)

Where,

h = substrate thickness

L = length of patch

W = width of patch

Lg = length of ground

Wg =width of ground

3.1.1 Width and length of microstrip Patch:

Width and length of the Patch having substrate FR4 Epoxy with relative permittivity of $\varepsilon_r = 4.4$ for the selected resonant frequency is given in the following table.

Table 3.1 for Width and length of microstrip Patch antennas:

Frequency(GHZ)	Width(mm)	Length(mm)
2.4	38.08	28.30
3.5	26.064	19.973
6	15.204	11.320
7	13.032	9.577
10.5	10.136	7.242

3.1.2 Effective Dielectric Constant:

Effective relative permittivity of patch having substrate FR4 Epoxy Glass of relative permittivity ε_r = 4.4, height of substrate (h = 1.6mm) and width of patch is given in the following table.

Table 3.2 for Width and Effective Dielectric Constant of microstrip Patch antennas:

Frequency(GHZ)	Width(mm)	Effective Dielectric Constant
2.4	38.08	4.08
3.5	26.064	3.998
6	15.204	3.85
7	13.032	3.803
10.5	10.136	3.723

3.1.3 Ground plane dimensions calculation (Lg and Wg)

Ground plane dimensions with substrate FR4 Epoxy Glass of relative permittivity ε_r = 4.4 and height of substrate (h = 1.6mm) is given in the following table.

Table 3.3 Ground plane dimensions for microstrip Patch antennas:

frequency	Length of the ground(mm)	Width of the ground(mm)
2.4	37.9	47.68
3.5	29.573	35.664
6	20.92	24.804
7	19.177	22.632
10.5	16.842	19.736

3.1.4 Inset feed depth determination (y0)

An inset-fed type feed is to be used in this design. As shown in Fig 3.1, the inset feed point depth must be located at point on the patch, where the input impedance is exactly 50 ohms for the resonant frequency. The optimum feed depth, where the reflection coefficient is at the minimum value, is calculated as per equation (2.12). Minimum reflection coefficient indicates minimum return loss and there exists a point along the length of the patch which gives the minimum return loss.

The Inset length for microstrip patch antenna which resonate at the given center frequency and patch length is given in the following table.

Table 3.4 Inset length

frequency	Length of the patch (mm)	Inset dimension(mm)
2.4	28.30	10.8781
3.5	19.973	6.13477
6	11.320	3.4769
7	9.577	2.9416
10.5	7.242	0.021

3.2 Design of CPW fed coplanar patch antenna for S, C and X band Application using rectangular patch

A coplanar waveguide can be quasi-statically analyzed by the use of conformal mappings. Since the substrate has a finite thickness h, to carry out the analysis of this conformation, a preliminary conformal mapping transforms the finite thickness dielectric into an infinite thickness. In this analysis, the coplanar waveguide conductors and the dielectric substrates are assumed to have perfect conductivity and relative permittivity respectively. Hence the structure is considered to be lossless. Furthermore, the dielectric substrate material is considered to be isotropic. In this analysis, expressions for determining effective relative permittivity (ε_{reff}) and Z0 using conformal mapping techniques are presented. The assumptions made are that the conductor thickness t is negligible and magnetic walls are present along all the dielectric boundaries including the coplanar waveguide slots. The coplanar waveguide is then divided into several partial regions and the electric field is assumed to exist only in that partial region. In this manner the capacitance of each partial region is determined separately. The total capacitance (CCPW) is then the sum of the partial capacitances. In this case the partial capacitances are capacitance due to substrate (C1) and capacitance due to air (Cair). Therefore, the total capacitance can be given as [9]:

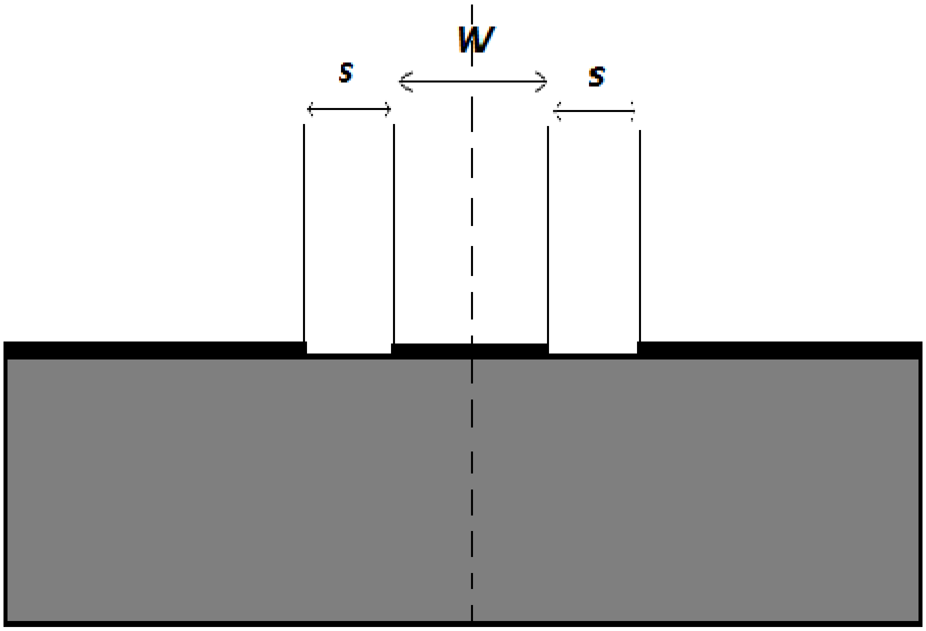

Fig. 3.2 Side view of a Coplanar Waveguide [9]

The design of a coplanar patch antenna is very similar to that of a microstrip patch antenna. The equations used in microstrip patch antenna design are also applicable for coplanar patch antenna design. The only difference being that the relative dielectric constant (Єreff) for a coplanar waveguides is different. The Єreff for a coplanar waveguide is calculated as follow [9].

$$C_{CPW} = C_1 + C_{air} \qquad \text{...} \quad (3.9)$$

Where capacitance due to substrate (C1) and capacitance due to air (Cair) as given in [9]:

$$C_1 = 2\epsilon_o\,(\epsilon_r - 1).\frac{k(k2)}{k'(k2)} \quad \text{and} \quad C_{air} = 4\epsilon_o.\frac{k'(k1)}{k(k1)} \qquad \text{............} \quad (3.10)$$

Hence the total Capacitance as given in equation (3.9) can be written as:

$$C_{CPW} = 2\epsilon o\,(\epsilon r-1).\frac{k(k2)}{k'(k2)} + 4\epsilon o.\frac{k'(k1)}{k(k1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.11)}$$

Now using above capacitances values, effective dielectric constant can be given as [9]:

$$\epsilon reff = \frac{CCPW}{Cair} = w\ 1+\frac{\epsilon r-1}{2}.\frac{k(k2)}{k'(k2)}\frac{k'(k1)}{k(k1)} \quad \ldots\ldots\ldots\ldots\ldots\ \ldots \text{(3.12)}$$

Here K(k) and K'(k) represents the complete elliptical integral of the first kind and it's complement, and

$$K_1 = \frac{W}{W+2S} \text{ and } K_2 = \frac{\sinh\left(\frac{\pi w}{4h}\right)}{\sinh\left(\frac{\pi(w+2s)}{4h}\right)} \quad \ldots\ldots\ldots.\ .\ \ldots\ldots\ldots.. \text{(3.13)}$$

The impedance of such a coplanar transmission line is given as [9]:

$$zo = \frac{1}{Cair\sqrt{\epsilon reff}} = \frac{30\pi}{\sqrt{\epsilon reff}}\frac{k'(k1)}{k(k1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \text{(3.14)}$$

Where, c is the velocity of light in free space. The guided wavelength λg for a coplanar waveguide is given as

$$\lambda g = \frac{c}{fr\sqrt{\epsilon reff}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \text{(3.15)}$$

Using above equation for guided wavelength, dimension of the coplanar patch antennas are calculated. The length of the coplanar patch is approximately taken as λg/4 whereas the width of the patch is taken such that the length and width summation of the patch dimensions should not exceed λ_g. Here in this design the width is approximately taken as λ_g. The patch dimensions were optimized to resonate at this center frequency. The inset feed design equation for a microstrip patch antenna is applicable to coplanar patch antenna. The inset helps in matching the 50 **Ω** feed line to a particular point in the patch where the impedance is close to 50 **Ω**.

Length of the coplanar patch antenna will be given in equation (3.16).

$$Lp = \frac{C}{2fr\sqrt{\epsilon reff}} - 2\Delta L \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.16)$$

For calculating strip gap (S) the following equation is used [10]

$$fr = \frac{C}{\sqrt{2 * \epsilon reff}} \frac{4.6 * 10^{-14}}{S} + \frac{f}{1.01}$$

To obtain the desired resonance (fr) at the operating frequency f, i.e. fr = f

$$f - \frac{f}{1.01} = \frac{C}{\sqrt{2 * \epsilon reff}} \frac{4.6 * 10^{-14}}{S}$$

Rearranging the above equation for

$$S = \frac{C}{\sqrt{2 * \epsilon reff}} \frac{4.65 * 10^{-12}}{f} \ldots\ldots\ldots\ldots\ldots\ldots (3.17)$$

The strip gap (S) is located symmetrically along the width of the patch. The dimensions of the different parameters, shown Fig. 3.3, have been approximated using the above equations.

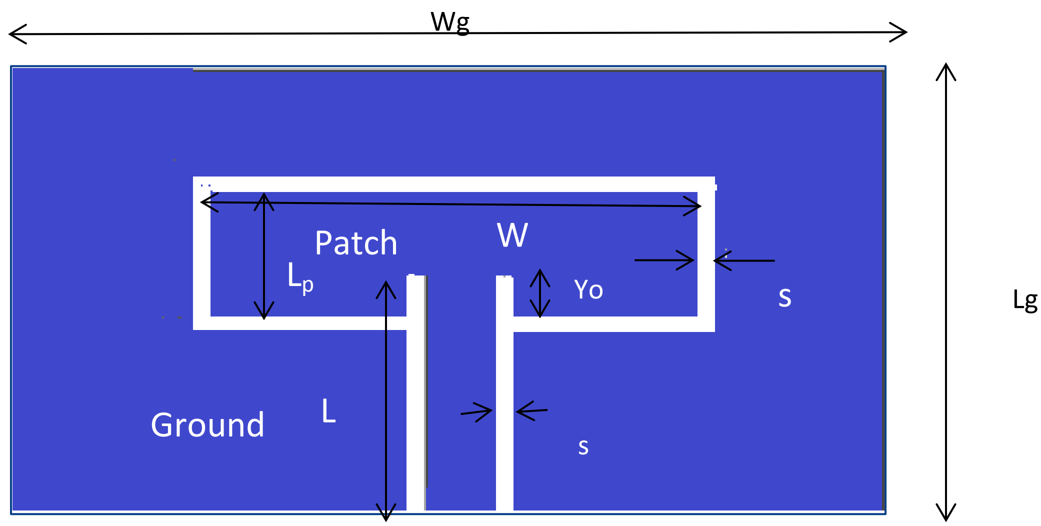

Figure 3.3 Schematic Diagram of Inset Fed Coplanar Patch Antenna

The coplanar patch antenna is designed on FR4 Epoxy Glass that has relative permittivity of 4.4, loss tangent = 0.0009 and thickness of the substrate is 1.6 mm. The strip gap (s) is taken as 0.56mm and width (W) of the coplanar waveguide feed is 3.124 mm. using the above equation coplanar antennas are designed for different operating frequency and results are placed in the following table. To make parameter comparison, results found for microstrip are also included in the following tables.

Observing the below Tables, it can be noted that with the increase in frequency the size of the antenna reduces. This validates the previously established concepts. Some other important conclusions, based on the simulation results, are also discussed in the next section.

Table 3.5 for 2.4 GHz patch antenna:

Element	Calculated results for coplanar patch antenna (mm)	Calculated results for microstrip patch antenna (mm)
Width of patch(W)	38.08	38.08
Length of patch(L)	32.203	28.30
Width of Ground(Wg)	47.636	47.636
Length of ground(Lg)	41.803	37.9
Inset length(Yo)	11.231	10.8781
Effective Dielectric Constant(Ereff)	3.701	4.08

Table 3.6 for 3.5 GHz patch antenna:

Element	Calculated results for coplanar patch antenna (mm)	Calculated results for microstrip patch antenna (mm)
Width of patch(W)	26.082	26.082
Length of patch(L)	22.063	19.973
Width of Ground(Wg)	35.682	35.682
Length of ground(Lg)	31.663	29.573
Inset length(Yo)	6.675	6.13477
Effective Dielectric Constant(Ereff)	3.6985	3.998

Table 3.7 for 6 GHz patch antenna:

Element	Calculated results for coplanar patch antenna (mm)	Calculated results for microstrip patch antenna (mm)
Width of patch(W)	15.215	15.215
Length of patch(L)	12.846	11.320
Width of Ground(Wg)	24.815	24.815
Length of ground(Lg)	22.446	20.92
Inset length(Yo)	3.654	3.4769
Effective Dielectric Constant(Ereff)	3.604	3.85

Table 3.8 for 7 GHz patch antenna:

Element	Calculated results for coplanar patch antenna (mm)	Calculated results for microstrip patch antenna (mm)
Width of patch(W)	13.041	13.041
Length of patch(L)	10.002	9.577
Width of Ground(Wg)	22.641	22.641
Length of ground(Lg)	20.602	19.177
Inset length(Yo)	3.041	2.9416
Effective Dielectric Constant(Ereff)	3.521	3.803

Table 3.9 for 10.5 GHz patch antenna:

Element	Calculated results for coplanar patch antenna (mm)	Calculated results for microstrip patch antenna (mm)
Width of patch(W)	10.116	10.116
Length of patch(L)	8.315	7.42
Width of Ground(Wg)	18.294	18.294
Length of ground(Lg)	16.915	15.842
Inset length(Yo)	2.942	2.87
Effective Dielectric Constant(Ereff)	3.467	3.723

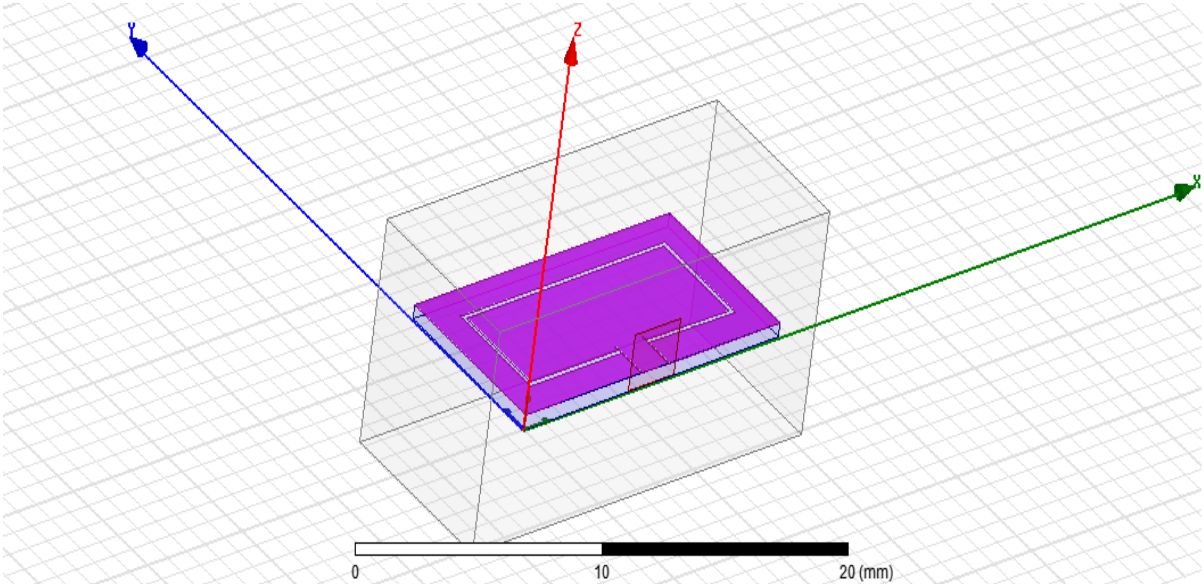

Figure 3.4 Model of Coplanar Patch Antenna in HFSS software

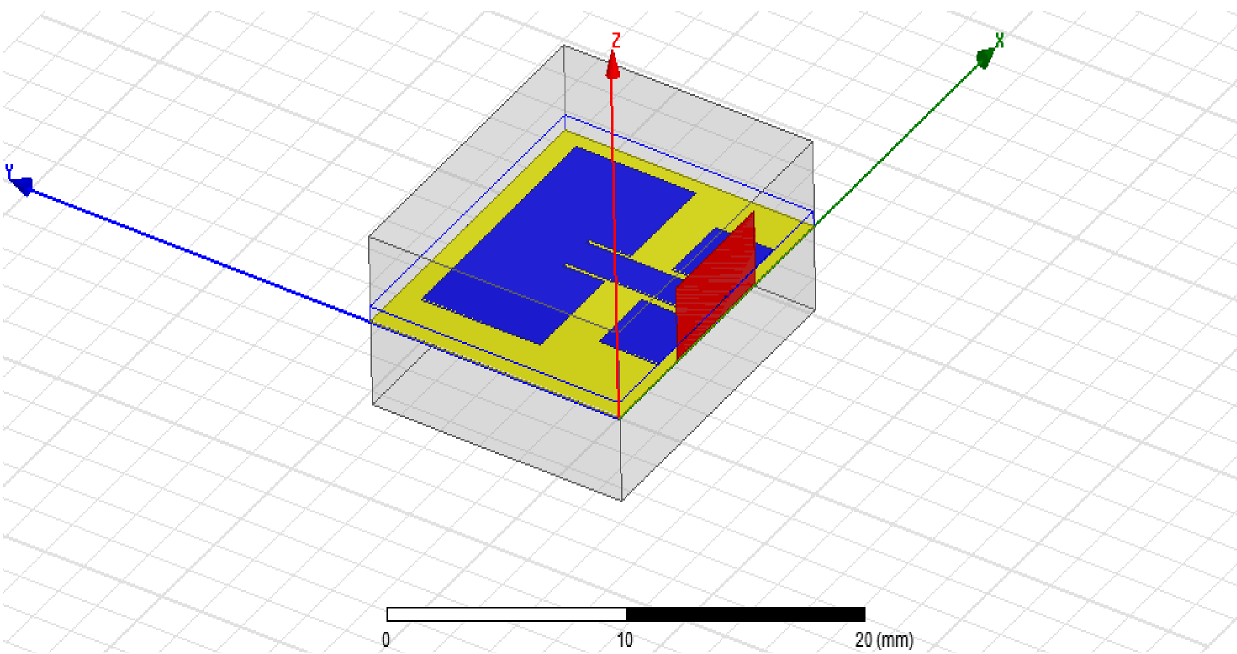

Figure 3.5: Model of Microstrip Patch Antenna in HFSS Software.

Chapter 4

Result and Discussion

4.1 Simulation Results for 2.4 GHz:

During simulation, the conducting grounds and the substrates were assumed to be finite in transverse plane.

The below HFSS result shows return loss in dB verses frequency of rectangular microstrip and coplanar patch antennas. At 2.4 GHz frequency the microstrip and coplanar patch antennas exhibit a reflection coefficient of -21.3579 dB and -19.5875 dB respectively. Meanwhile, the bandwidth of microstrip and coplanar antennas at -10dB is 5.825% (i.e.139.8MHz) and 18.604% (i.e. 446.5MHZ) respectively.

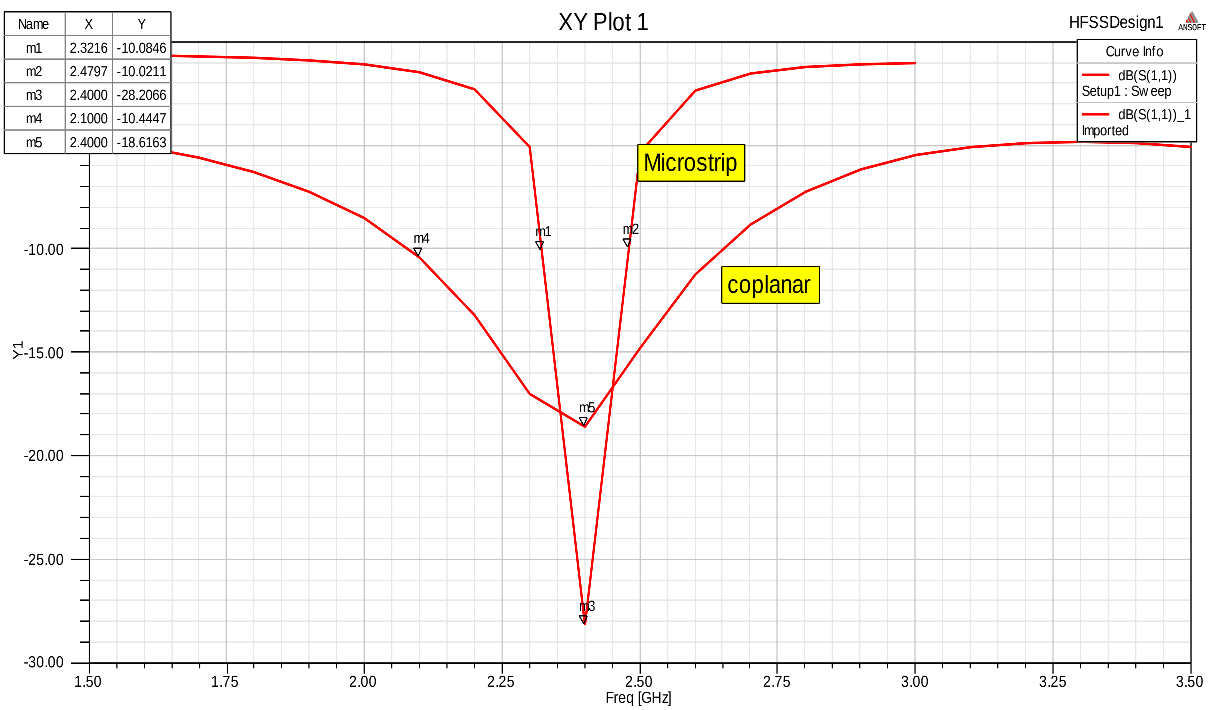

Figure 4.1 Return losses for microstrip and Coplanar patch antenna at 2.4 GHz

The radiation efficiency obtained for microstrip antenna is 87.54% and that for a coplanar patch antenna is 94.128 % i.e. 6.588 more efficient than that of microstrip patch antenna. Figure 4.2 and 4.3 shows the far field radiation pattern for microstrip and coplanar patch antennas at a solution frequency of 2.4 GHz respectively.

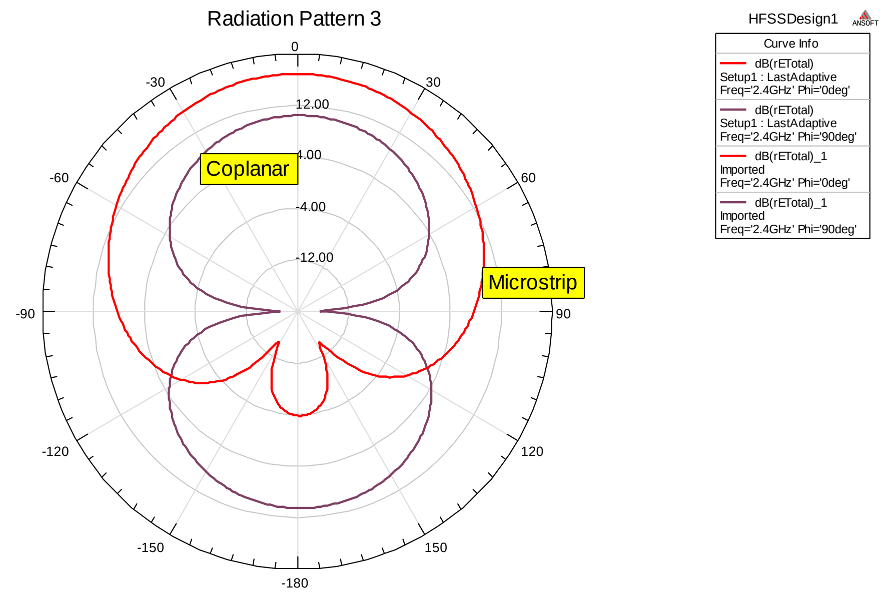

Figure 4.2 Radiation Pattern of 2.4 GHz microstrip patch antenna

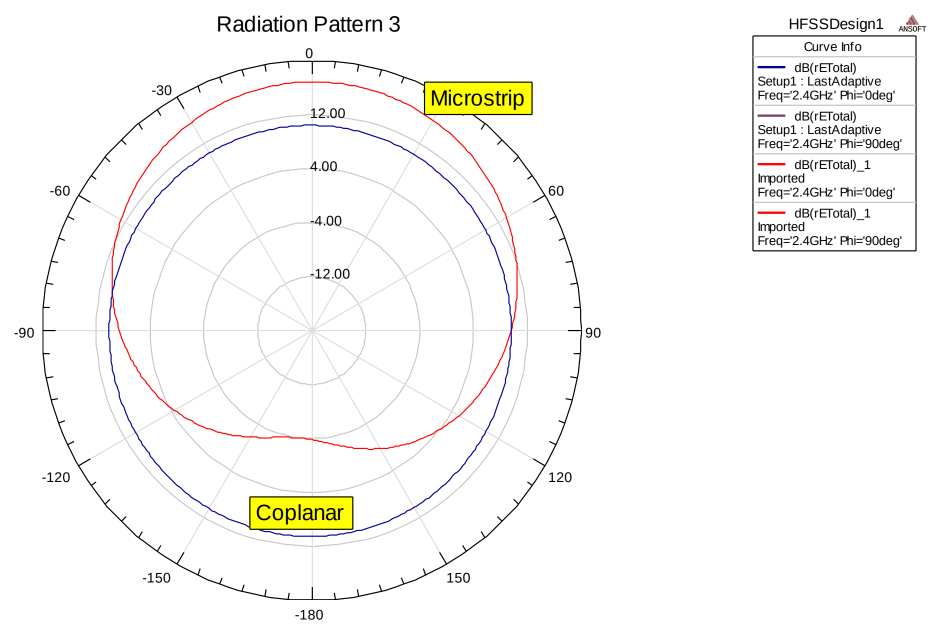

Figure 4.3 Radiation Pattern of 2.4GHz coplanar patch antenna

4.2 Simulation Results for 3.5 GHz:

At 3.5 GHz frequency the simulated microstrip antenna exhibits reflection coefficient of -21.6287 dB along with -10dB bandwidth of 5.254% (i.e.183.9MHz). Likewise, coplanar patch antenna exhibits reflection coefficient of -19.1740 dB along with-10dB bandwidth of 19.375% (i.e.620MHz).

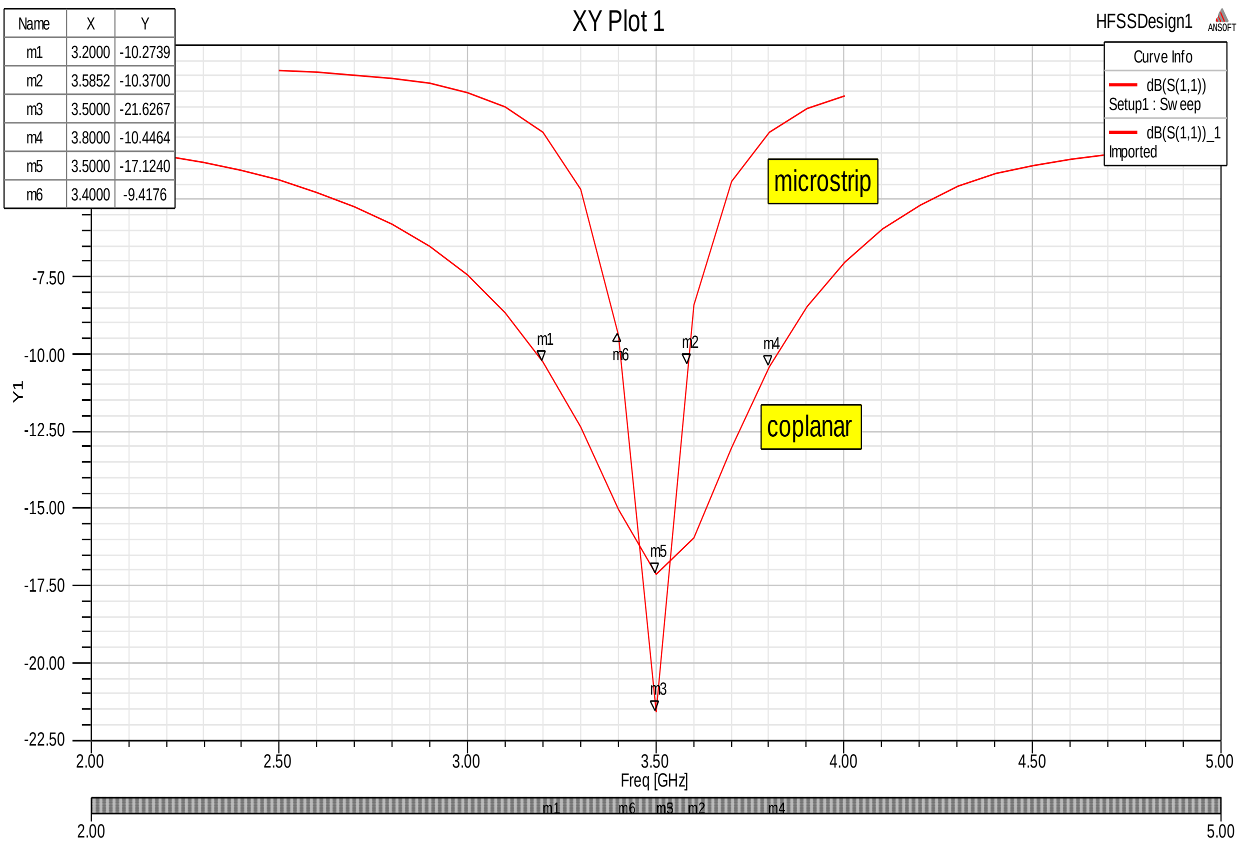

Figure 4.4 Return losses for microstrip and Coplanar patch antenna at 3.5 GHz

And the ability of the antenna to transform the received power in to electromagnetic wave (radiation efficiency) for coplanar antenna is 96.24% and that for a microstrip patch antenna is 82.342 % i.e. 13.898 more than the efficiency of the microstrip patch antenna. The far field radiation pattern (at Phi=0^0 and Phi=90^0) for microstrip and coplanar patch antenna at the operating frequency of 3.5GHz is depicted in Fig 4.5 and 4.6 respectively.

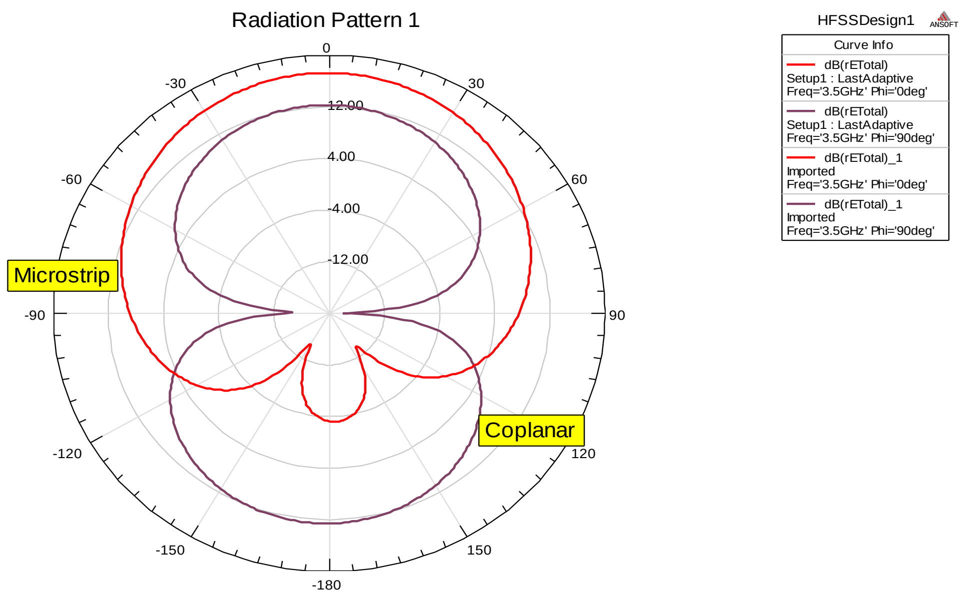

Figure 4.5 Radiation Pattern of 3.5 GHz microstrip and coplanar patch antenna at Phi=90^0

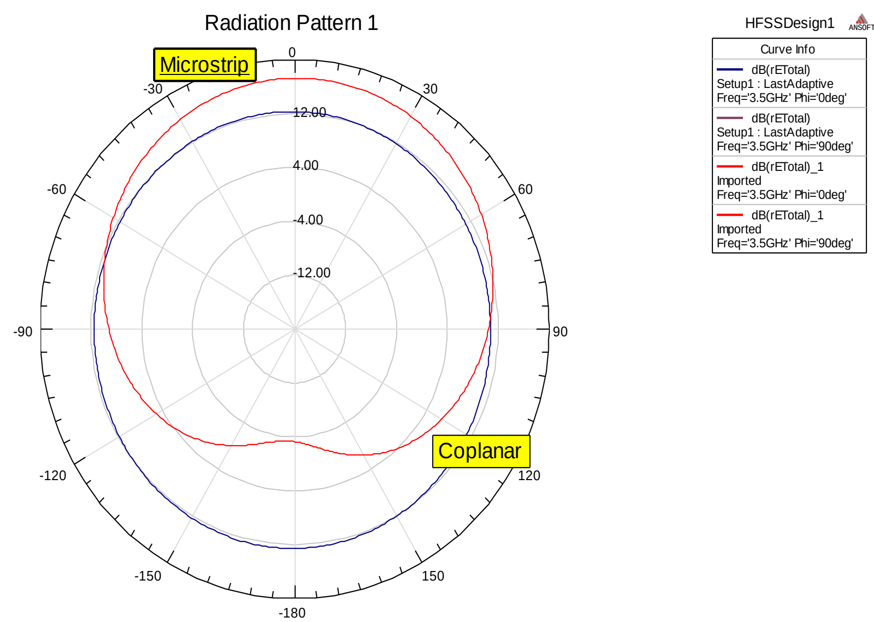

Figure 4.6 Radiation Pattern of 3.5 GHz microstrip and coplanar patch antenna at Phi=0^0

4.3 Simulation Results for 6 GHz:

At 6 GHz frequency the simulated microstrip and coplanar patch antennas exhibit reflection coefficient of -20.9381 dB and -29.0980 dB respectively. Bandwidth of microstrip antenna is 7 % (i.e. 409.4MHz) while 19.16% (i.e.1.15GHz).The radiation efficiency obtained for coplanar and microstrip patch antenna is 92.31% and 84.645% respectively.

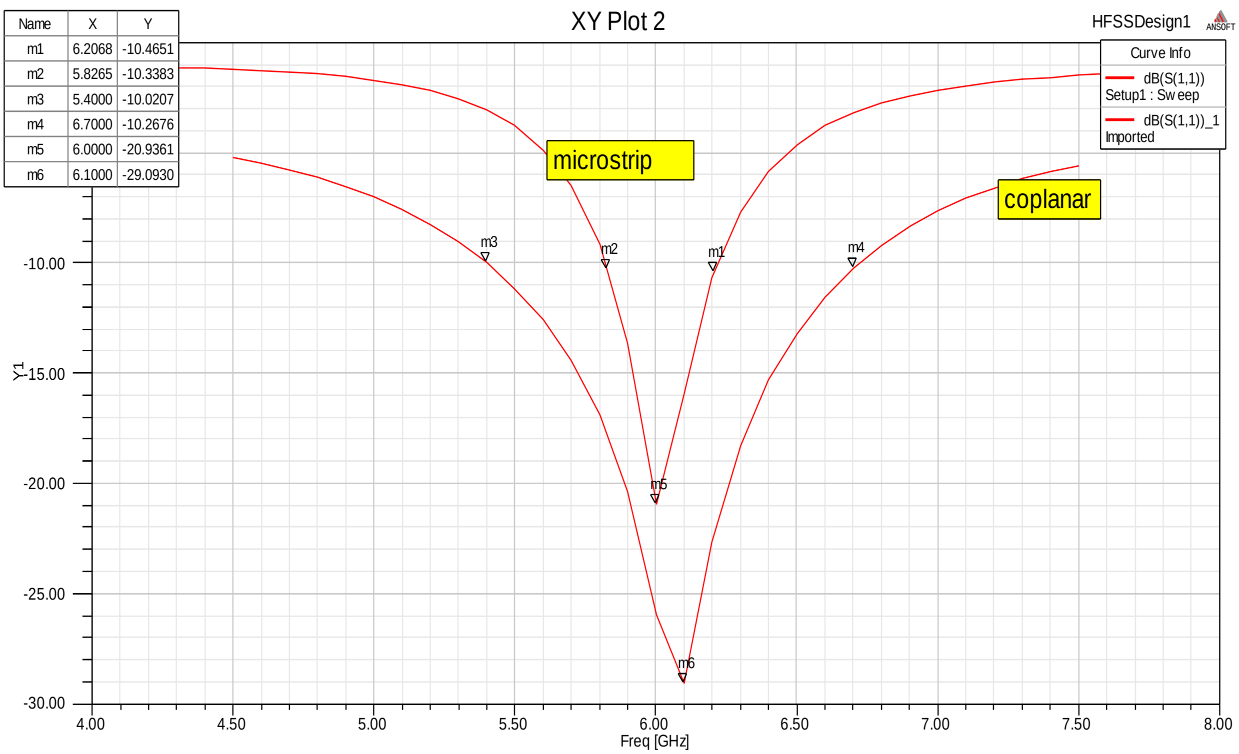

Figure 4.7 Return losses for microstrip and Coplanar patch antenna at 6 GHz

The far field radiation pattern for microstrip and coplanar patch antennas at a solution frequency of 6 GHz is depicted in Fig. 4.8 and 4.9 respectively.

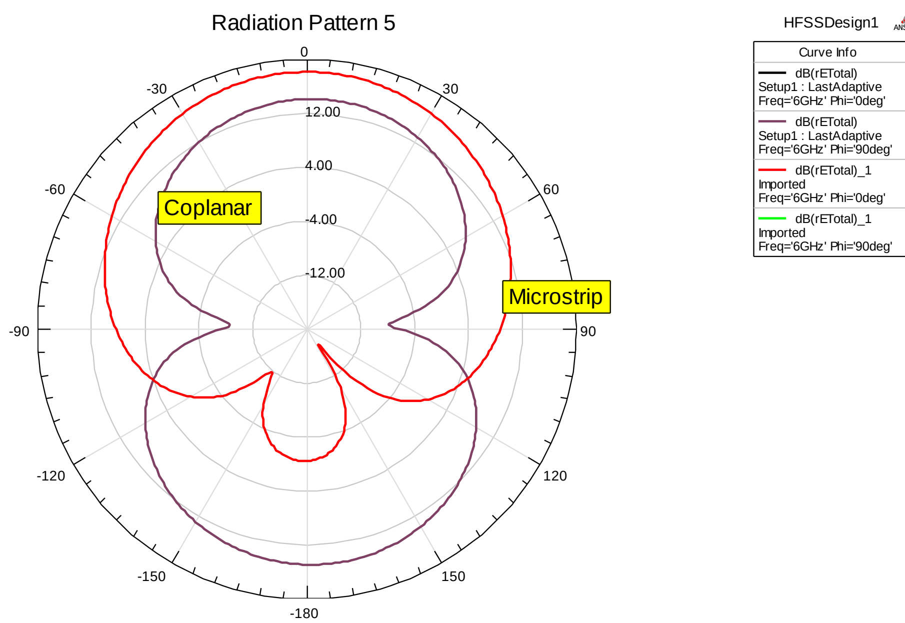

Figure 4.8 Radiation Pattern of 6 GHz microstrip and coplanar patch antenna at Phi=90^0

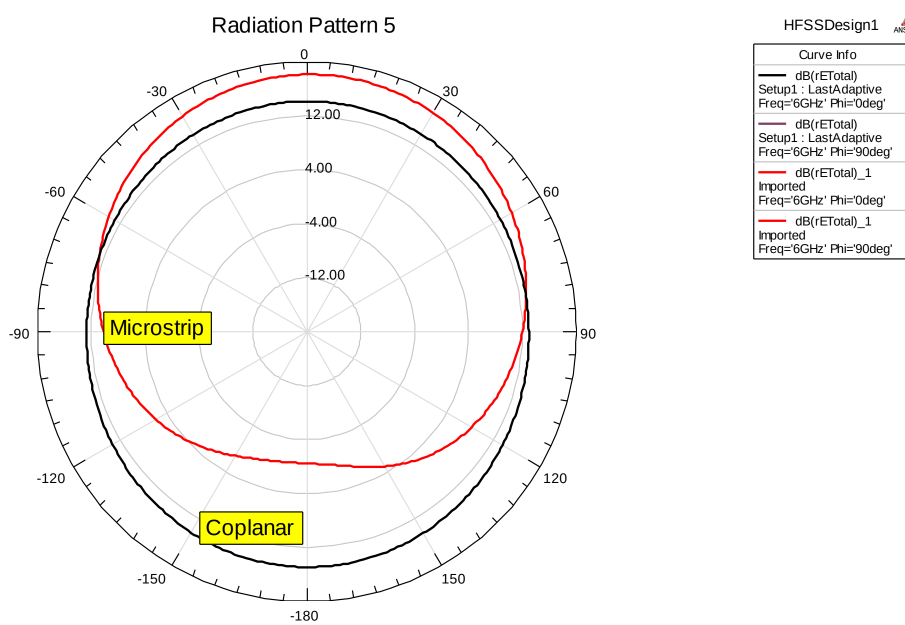

Figure 4.9 Radiation Pattern of 6 GHz microstrip and coplanar patch antenna at Phi=0^0

4.4 Simulation Results for 7 GHz:

At 7GHz frequency the designed microstrip patch antenna exhibit a reflection coefficient of -31.39845 dB along with -10dB bandwidth of 5.97 % (i.e.480MHz). Likewise, coplanar patch antenna exhibits reflection coefficient of -25.9068dB and 8.357 % (i.e.585 MHz) bandwidth. The radiation efficiency obtained for coplanar antenna is 93.81% and that for a microstrip patch antenna is 86.486 % i.e. 7.324 more efficient than microstrip patch antenna.

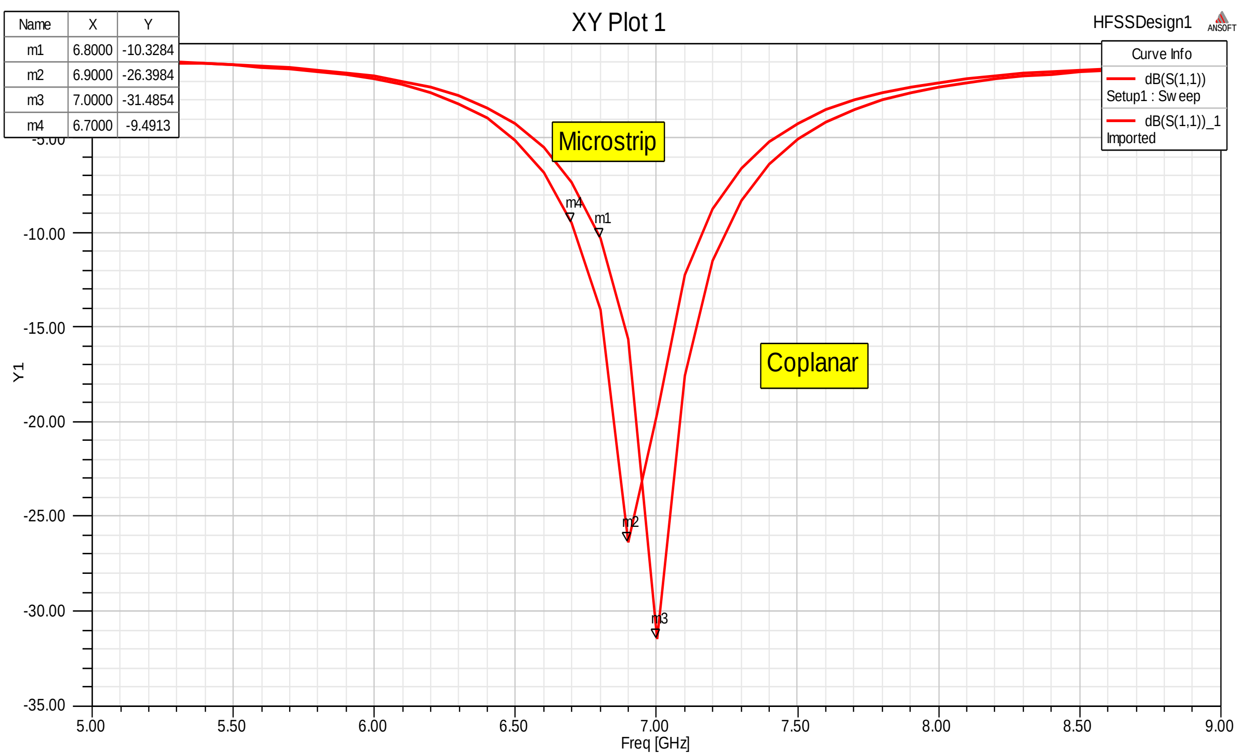

Figure 4.10 Return losses for microstrip and coplanar patch antenna at 7 GHz

The radiation efficiency obtained for coplanar antenna is 93.81% and that for a microstrip patch antenna is 86.486 % i.e. 7.324 more efficient than microstrip patch antenna .The far field radiation pattern for microstrip and coplanar antennas at a solution frequency of 7 GHz is depicted in Fig. 4.11 and 4.12 respectively.

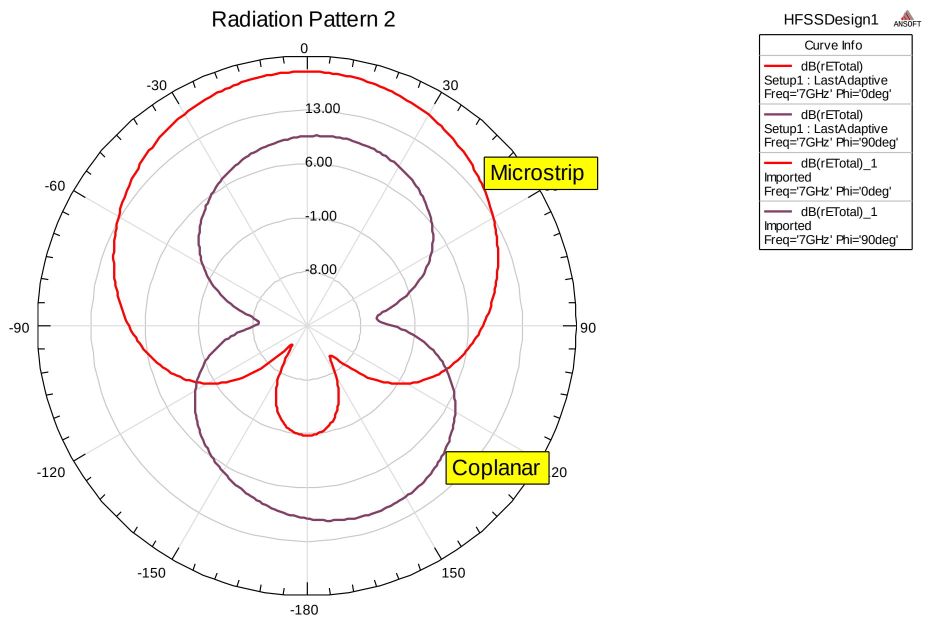

Figure 4.11 Radiation Pattern of 7GHz microstrip and coplanar patch antenna Phi=90^0

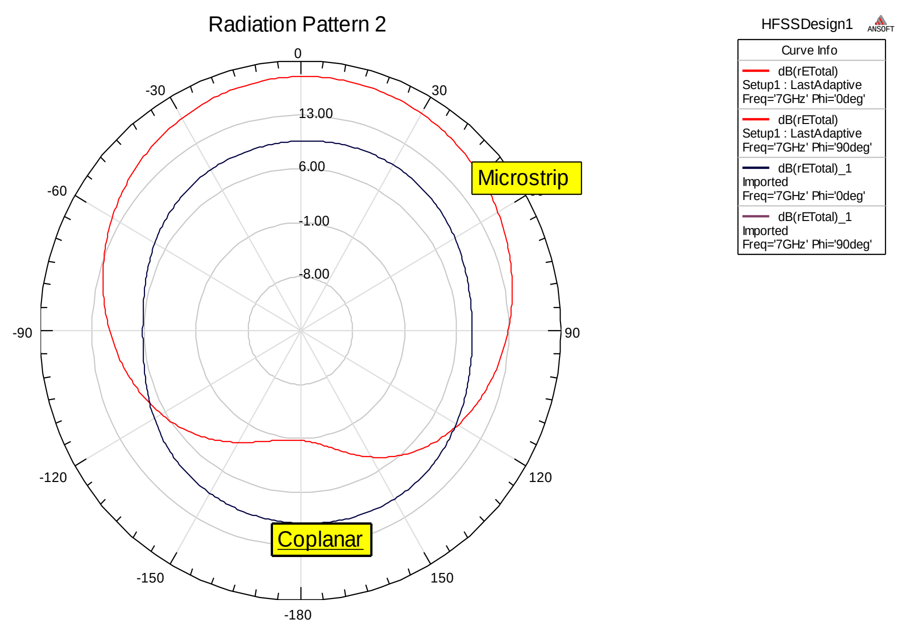

Figure 4.12 Radiation Pattern of 7 GHz microstrip and coplanar patch antenna at Phi=0^0

4.5 Simulation Results for 10.5 GHz:

Reflection coefficient of microstrip and coplanar patch antennas at 10.5 GHz is -25.4574 dB and -16.5866 dB respectively. Bandwidth along -10dB for microstrip antenna is 3.8 % (i.e. 393.6 MHz) while for coplanar patch antenna it is 17.75% (i.e. 1.785GHz). Similarly, the radiation efficiency obtained for coplanar antenna is 98.78% and that for a microstrip patch antenna is 89.231 % i.e. 9.549 more than the efficiency of the microstrip patch antenna.

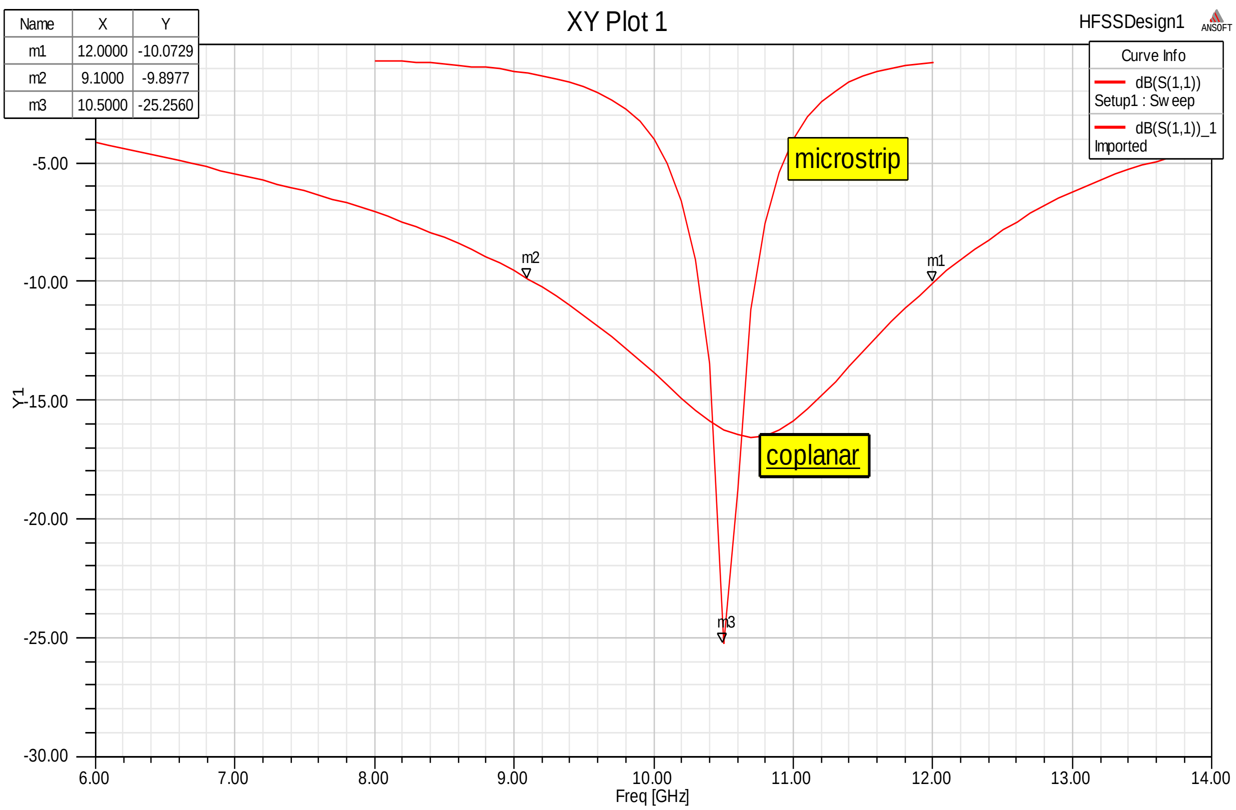

Figure 4.13 Return losses for microstrip and coplanar patch antenna at 10.5 GHz

The far field radiation pattern for microstrip and coplanar antennas at a solution frequency of 10.5 GHz is depicted in Fig. 4.14 and 4.15 respectively.

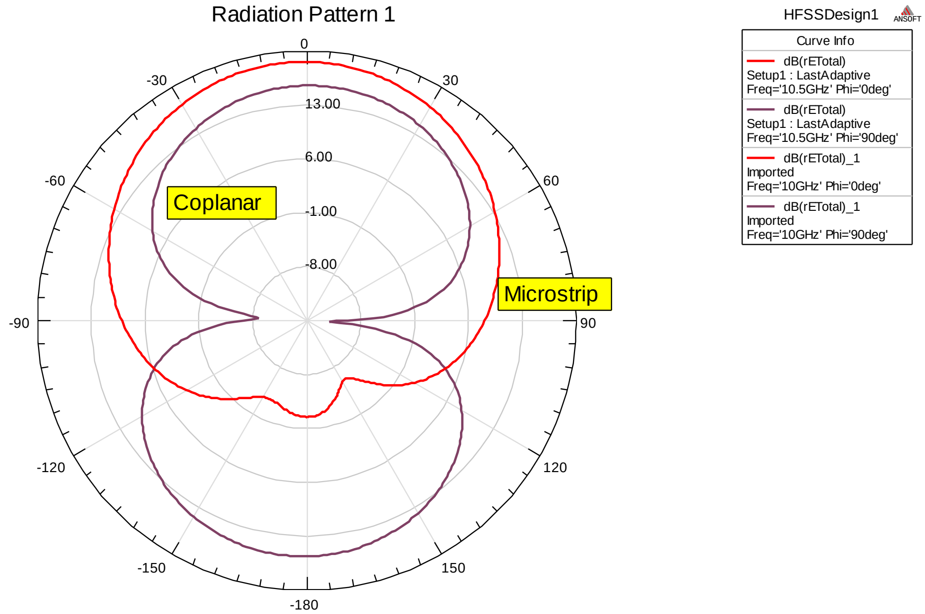

Figure 4.14 Radiation Pattern of 10.5GHz microstrip and coplanar patch antenna Phi=90^0

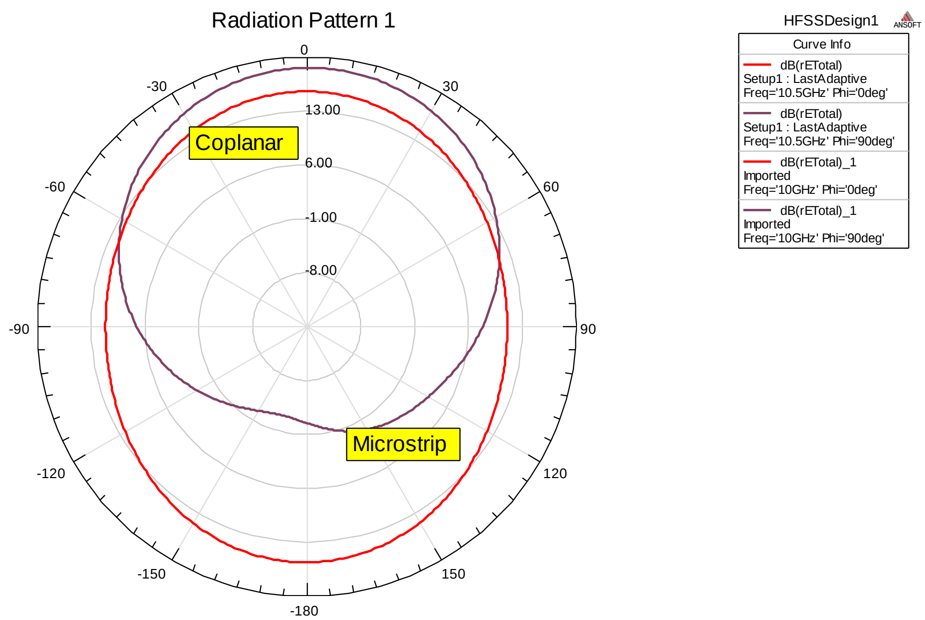

Figure 4.15 Radiation Pattern of 10.5 GHz microstrip and coplanar patch antenna at Phi=0^0

The following figures show 3-D polar plots for microstrip and coplanar patch antennas at 10.5 GHz.

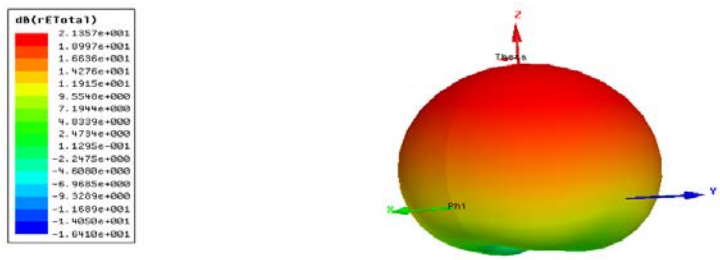

Figure 4.16   3-D polar plots for microstrip patch antenna at 10.5GHz.

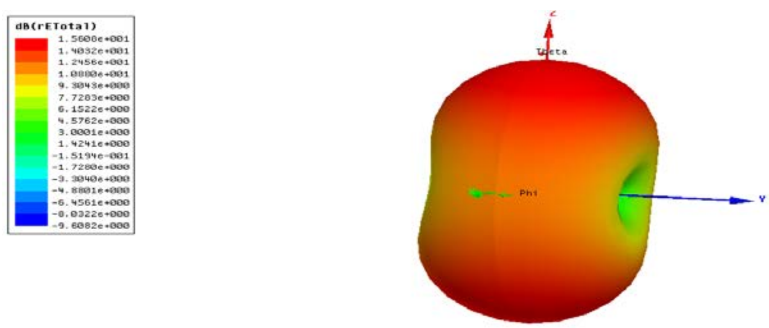

Figure 4.17   3-D polar plots coplanar patch antenna at 10.5GHz.

Table 4.1 HFSS Simulation result summary

	Frequency (GHz)	Return loss (-dB)	Bandwidth(MHz) (-10dB)	Radiation efficiency (%)	Directivity(dB)
Microstrip	2.4	21.3579	139.8	87.54	7.65
	3.5	21.6287	183.9	82.342	6.49
	6	20.9381	409.4	84.645	7.69
	7	31.4854	480	86.486	7.24
	10.5	25.4574	393.6	89.231	5.352
coplanar	2.4	19.5875	446.5	94.128	4.87
	3.5	19.1740	620	96.24	3.69
	6	29.0980	1150	92.31	5.69
	7	25.9068	585	93.81	4.675
	10.5	16.5866	1785	98.78	2.79

The HFSS Simulation result summary has shown that, for the same operating frequency and substrate, coplanar patch antennas gives wider bandwidth and higher radiation efficiency than microstrip patch antenna. This is due to the fact that, the effective dielectric constant for a coplanar antenna design is lower than microstrip antenna design. When effective dielectric constant of the patch decreases the surface wave excitation will reduced to a large extent, which in turn, leads to a lower radiation loss and less dispersion. Due to this reason coplanar antennas have high radiation efficiency and wider bandwidth.

For operating frequencies 2.4 GHz, 3.5 GHz, 6GHz, 7 GHz and10.5GHz return loss for microstrip patch antennas is found to be lower than coplanar patch antennas. It is related to impedance matching and the maximum transfer of power. It also shows the effectiveness of the designed antennas to deliver of power from source to antenna. Even if the same feeding (coplanar wave guide) and impedance matching techniques(inset) are applied for both antennas , microstrip patch antennas give lower return loss (higher in the negative) than coplanar patch antennas.

The VSWR for the two antennas is in between 1 to 2 over the entire frequency band which shows that there is a proper impedance matching.

The result summary has also shown that directivity for microstrip patch antennas is higher than that of coplanar patch antennas. The reason for the low directivity in case of coplanar patch antenna is that, it has patch and ground on the same plane so that the electric field below the patch also form a lobe on the other side of the patch forming a broadside pattern, whereas in case of microstrip patch the fields below the patch are shorted by the lower ground making a single lobe in one direction above the patch forming a unidirectional pattern.

Chapter 5

Conclusion and Recommendation for Future Work

5.1 Conclusion

In this paper, a CPW fed rectangular-shaped microstrip and coplanar patch antenna are designed with the application of inset fed for impedance matching. The microstrip patch antenna consists of a pair of electrically conducting layers separated by a 1.6 mm dielectric material. Likewise coplanar patch antenna consists of a pair of electrically conducting layers placed over a 1.6 mm dielectric material with permittivity of 4.4. The antenna efficiency, return loss, bandwidth, radiation pattern and VSWR (<2) are obtained for both microstrip and coplanar patch antennas.

Full wave HFSS simulation of coplanar and microstrip patch antenna models shows that for same operating frequency and same substrate, coplanar patch antenna gives wider bandwidth and high radiation efficiency than microstrip patch antenna. On the other side, microstrip patch antennas are more compact (lower profile) than coplanar patch antennas.

From the simulation observations and result summary, it can be concluded that CPW fed coplanar antenna has got low directivity than microstrip patch antenna. The reason for the low directivity in case of coplanar patch antenna is that it has patch and ground on the same plane so the electric field below the patch also form a lobe on the other side of the patch forming a broadside pattern. But the directivity of the coplanar patch antenna can be improved by providing another conductor (or ground) below the substrate; such designs are called as Conductor Backed Coplanar Patch Antennas.

Since microstrip patch antenna is more directional than coplanar patch antennas it provides radiation patterns that are stable across the pass band, and are easy to integrate with other microwave circuits and devices. In the meantime coplanar patch antennas offer better bandwidth and radiation efficiency.

These antennas can be used for several applications specially 2.4 GHz for Bluetooth, 3.5 GHz for WIMAX, 6 GHz for WLAN, 7 GHz for Ultra- Wide Band Communication, and 10.5 GHz for reception of SART (Search and Rescue Transponders) for signals coming from X-band radars.

5.2 Recommendation and Future work

Finally, it is recommended that using conductor backed coplanar wave guide (CCPW) helps to increase the directivity of coplanar patch antenna. And for the future it is possible to analyze the performance of the two antennas by using conductor backed coplanar wave guide feeding system. The future work should also address the performance comparison of the two antennas for different patch geometry and multiband applications.

Appendix A

High Frequency Structural Simulator (HFSS)

Ansoft High Frequency Structure Simulator is a full-wave, FEM-based electromagnetic field solver for simulating arbitrary (3D) structures. HFSS is used to simulate Connectors Waveguides On-chip components Antennas etc and used for parametric sweeps Structure optimization etc.

HFSS is based on a three-dimensional FEM, a frequency domain method (solutions are calculated for each frequency separately). FEM divides the whole model space into small finite elements (triangles or tetrahedral) and represents the field in each subdomain with a local function for the volume of total of N sub-domains, the scattered field can be expanded into a series of known basis functions with unknown expansion coefficients. The value of a vector field quantity at points inside each tetrahedral is numerically interpolated from the values at the vertices and the midpoints of the edges. The simulator transforms Maxwell's equations into matrix equations, which can be solved using numerical methods. The simulation time is proportional to N (when solved iteratively) or N^3 (if system matrix is inverted directly).

The Adaptive Analysis Process (from HFSS help)

An adaptive analysis is a solution process in which the mesh is refined iteratively in regions where the error is high, which increases the solution's precision. You set the criteria that control mesh refinement during an adaptive field solution. Many problems can be solved using only adaptive refinement.

- HFSS generates an initial mesh.
- Using the initial mesh, HFSS computes the electromagnetic fields that exist inside the structure when it is excited at the solution frequency. (If you are running a frequency sweep, an adaptive solution is performed only at the specified solution frequency.)

- Based on the current finite element solution, HFSS estimates the regions of the problem domain where the exact solution has strong error. Tetrahedral in these regions are refined.
- HFSS generates another solution using the refined mesh.
- HFSS re-computes the error, and the iterative process (solve error analysis refine) repeats until the convergence criteria are satisfied or the requested number of adaptive passes is completed.
- If a frequency sweep is being performed, HFSS then solves the problem at the other frequency points without further refining the mesh.

Frequency Sweeps (from HFSS help)

Perform a frequency sweep when you want to generate a solution across a range of frequencies. You may choose one of the following sweep types:

- **Fast**: Generates a unique full-field solution for each division within a frequency range. Best for models that will abruptly resonate or change operation in the frequency band. A Fast sweep will obtain an accurate representation of the behavior near the resonance.
- **Discrete**: Generates field solutions at specific frequency points in a frequency range. Best when only a few frequency points are necessary to accurately represent the results in a frequency range.
- **Interpolating**: Estimates a solution for an entire frequency range. Best when the frequency range is wide and the frequency response is smooth, or if the memory requirements of a Fast sweep exceed your resources.

Excitations (from HFSS help)

Assigning excitations to an HFSS design enables you to specify the sources of electromagnetic fields and charges, currents, or voltages on objects or surfaces.

- Wave port
- Lumped port
- Incident wave
- Voltage source
- Current source
- Magnetic Bias source

Boundaries (from HFSS help)

Boundary conditions specify the field behavior on the surfaces of the problem region and object interfaces. This area of the technical notes includes information about the following boundary types:

- Perfect E
- Perfect H
- Impedance
- Radiation
- PML
- Finite Conductivity
- Symmetry
- Master and Slave
- Lumped RLC
- Layered Impedance
- Infinite Ground Planes

Solution Types (from HFSS help)

- **Driven Modal Solution**

Choose the Driven Modal solution type when you want HFSS to calculate the modal-based S-parameters of passive, high-frequency structures such as microstrip, waveguides, and transmission lines. The S-matrix solutions will be expressed in terms of the incident and reflected powers of waveguide modes.

- **Driven Terminal Solution**

Choose the Driven Terminal solution type when you want HFSS to calculate the terminal-based S-parameters of multi-conductor transmission line ports. The S-matrix solutions will be expressed in terms of terminal voltages and currents.

- **Eigen mode Solution**

Choose the Eigen mode solution type to calculate the Eigen modes, or resonances, of a structure. The Eigen mode solver finds the resonant frequencies of the structure and the fields at those resonant frequencies.

The pros and cons of using the HFSS simulator are listed in table below:

Pros	Cons
➢ Large problems can be solved (matrix equations are simple leads to a sparse system matrix) ➢ Arbitrary objects can be simulated ➢ Automatic mesh refinement ➢ Extremely versatile ➢ Large number of different excitation/boundary types ➢ Very useful for simulating periodic structures ➢ User-defined plots ➢ Optimization procedures ➢ Easy to learn and use	➢ Entire volume must be Discretized ➢ Large matrices equations have to be solved (most simulations take too long when using an average PC)

Appendix B

Matlab code to calculate dimensions of the patch antenna

```
function[] = cal
global k0 W L
f = input( 'input frequency f in Ghz: ');
Er = input ( 'input dielectric constant of the substrate Er ');
h = input( 'input height of substrate h in mm: ');
h=h/1000; %turns height to meters
f=f*1e9; % turn frequency to HZ
c = 3e8; % speed of light
k0=2*pi*f/c; %wave number
Rin = 50; %required input impedance of the antenna
% calculating Width and Length of the Patch
W = ( c / ( 2 * f ) ) * ( ( 2 / ( Er + 1 ) )^0.5);
Er_eff = (Er+1)/2 + (( Er -1 )/2)*(1/(sqrt(1+(12*(h/W)))));
L_eff = c/(2*f*sqrt(Er_eff));
a1 = ( Er_eff + 0.3 ) * ( ( W / h ) + 0.264 );
a2 = ( Er_eff - 0.258 ) * ( ( W / h ) + 0.8 );
delta_L = (0.412 * ( a1 / a2 )) * h;
L = L_eff - 2*delta_L;
% calculating the distance of the inset feed point
t = 0:pi;
g1(t);
I1 = quad(@g1,0,pi);
G1 = I1/(120*pi*pi);
g12(t);
I12 = quad(@g12,0,pi);
G12 = I12/(120*pi*pi);
yo = (L/pi)*(acos(sqrt(2*Rin*(G1+G12))));
str=['width = ', num2str(W*1000), ' mm']
str=['length = ', num2str(L*1000), ' mm']
str=['the inset feed point distance = ', num2str(yo*1000), ' mm']
h=h/100;
%subfunktions
function [f] = g1(t)
global k0 W
f = ((sin(k0*W*0.5*cos(t))/cos(t)).^2*(sin(t)).^3);
function [k] = g12(t)
global k0 W L
k
=(((sin(k0*W*0.5*cos(t))/cos(t)).^2)*(sin(t).^3)).*BESSELJ(0,k0*L*sin(t));
```

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