TRIPLE BAND MICROSTRIP PATCH ANTENNA FOR PUBLIC PROTECTION AND DISASTER RELIEF USING APERTURE COUPLED FEED

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DR. PRADEEP KUMAR

by

KHUSHVINDER

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

SOLAN – 173 234, INDIA

Roll No. 132008 **MAY-2015**

DECLARATION

I, KHUSHVINDER, hereby declare that thesis entitled "DESIGN OF TRIPLE BAND MICROSTRIP PATCH ANTENNA USING APERTURE COUPLED FEED FOR PUBLIC PROTECTION AND DISASTER RELIEF", has been carried out by me under the supervision of Dr. Pradeep Kumar, Department of Electronics and Communication Engineering, Jaypee University of Information Technology, Wakhnaghat, Solan-173234, Himachal Pradesh, and has not been submitted for any degree or diploma to any other university. All assistance and help received during the course of the investigation has been dully acknowledged.

Date KHUSHVINDER

ABSTRACT

Public Protection and Disaster Relief (PPDR) is a matter of great concern for the citizens, the Governments and RF solutions are an essential element for Public Safety operations. Currently, all public safety communication system in India use narrowband radios. The narrowband nature of these system restrict them to 2-way voice communications with no additional support for high-bandwidth transmission requirements such as high quality photographs, interactive video communication, floor plans and remote video surveillance of security or disaster sites. Usually, a radiating structure is required to support multiple standards. The performance and advantages of microstrip patch antennas such as low weight, low profile, and low cost made them the perfect choice for communication systems engineers to be used for PPDR.

The aim of this dissertation is to develop a microstrip Patch Antenna that exhibits the high-bandwidth requirements within WiMAX and public safety bands. WiMAX (Worldwide Interoperability for Microwave Access) is the best suited for the application, as WiMAX has three allocated frequency bands from 2.5 -2.8 GHz, 3.2-3.8 GHz and 5.2-5.8 GHz. A triple band Microstrip Patch Antenna is designed that operates at 3.6 GHz, 5.2 GHz and 5.8 GHz. Only two i.e. middle band and high band is incorporated in the antenna to support high bandwidth requirements. The 3rd band used for Public safety band i.e. 5.850-5.925 GHz (according to IND73 of the National Frequency Allocation Table for PPDR in India). Since microstrip patch antennas have a low bandwidth, a special feeding technique named aperture coupling was implemented. This technique helps and makes it possible to use a low permittivity patch substrate with a large thickness. With the help of this configuration a broadband microstrip patch antenna can be realized. The U slots are used to ensure the triple band operation, helped in increasing the bandwidth and give the efficient results. The antenna is designed using CST Microwave Studio 2010.

Antenna's parameters are examined in this study include the dimensions and locations of the physical elements like feed line, ground plane coupling slot, and the patch. The operating frequency input VSWR, percent bandwidth, directivity, and gain are determined. Finally the benefits and drawbacks of aperture coupled antenna technology is studied, conclusions will be

drawn as to whether aperture-coupled antenna technology warrants further research and development along with the proposed design.

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Khushvinder

Contents

Chapter 1

1.1 OVERVIEW

On December 12, 1901, Guglielmo Marconi successfully received the first transatlantic radio message [1]. The message was the Morse-code for the letter ‘S’ – three short clicks. This event was notably the most important achievements in early radio communication. It was James Clerk Maxwell who originality developed the equations that express all the basic laws of electromagnetism and unified the domain of electricity, magnetism and light [2].At that time the communication system, while technically functional, clearly had a long room for improvement.

As, today in 21st century the system performance and efficiency has very significantly improved in the field of wireless communication. Wireless communication technologies are emerging at a rapid rate. Development in the fields of electronics, information theory, signal processing, and antenna theory have all contributed to the ubiquity of wireless communication systems as we see today. Today, researchers/scientists mainly focus on the fifth generation technologies and new accessing techniques. Wireless communication is the fastest growing segment of the communication industry. It has captured the attention of the media and the imagination of the public who suppose to use highspped application. Cellular systems have experienced exponential growth over the last few decades [3].

As improving public safety is a key challenge. The scientific community has paid a great attention to PPDR focusing on development of efficient Wireless Communication System for Emergency management and Disaster Relief [4]. Currently, all public safety communication system in India use narrowband radios. These employ narrowband channels and are operated on spot frequencies that are allocated to different public safety entities on a case-by-case basis. The narrowband nature of these radios restrict them for high-bandwidth transmission requirements such as interactive video communication, floor plans, remote video surveillance of security or disaster sites In an emergency situation communications systems with capability to support services beyond simple voice communications can prove to be life saving for the public safety personnel and civilians alike[5]. Wireless devices are used because of their capability to give connectivity to heterogeneous services operated with different mobile devices like smart phones, PDAs and laptops. Microstrip antenna is used because of useful properties such as small size, low-cost fabrication, low profile, light weight, conformability, ease of installation and integration with feed networks [6].

For all that, the design of a microstrip antenna is not always an easy problem. The challenges of MSA are low efficiency, narrow bandwidth of less than 5%, excitation of surface waves, Complex feed structures required for high performance arrays, low RF power due to the small separation between the radiation patch and the ground plane. Therefore, a MSA is required to deal with the high bandwidth requirements and operating at public safety band to give requisite results in terms of antenna parameters (discussed in chapter 4). A Triple Band Microstrip Patch Antenna using Aperture Coupling, is proposed to meet the requirements.

Thanks to the tremendous advances in aperture coupling, CST MWS 2010 with advance feature for system devices and system components, and IEEE 802.16 working group that has established a new standard known as WiMAX (Worldwide Interoperability for Microwave Access). The primary goal of this dissertation is to develop a Microstrip Patch Antenna that exhibits the high-bandwidth requirements within WiMAX and public safety bands. The influence of MSA geometry on wireless system performance. It will be shown that performance gains can be obtained via intelligent dimension selection of the antenna structure. Antenna structure therefore be hoped to contribute to the continuing advancement of wireless communication system performance.

1.2 LITERATURE SURVEY

The concept of printed antennas was originally proposed by Deschamps in 1953 [7] However, it took more than twenty years until Munson realized the first microstrip antenna [8]. The Microstrip Patch Antenna is a single-layer design which consists generally of four layers (patch, ground plane, substrate, and the feeding part). Patch antenna can be classified as single element resonant antenna. Once the frequency is given, everything (such as radiation pattern input impedance, etc.) is fixed. The advantages of the microstrip antennas are small size, low profile, and lightweight, conformable to planar and non planar surfaces. The main disadvantages of the microstrip antennas are: low efficiency, narrow bandwidth of less than 5%, low RF power due to the small separation between the radiation patch and the ground plane. The bandwidth of the microstrip patch antenna depends on the resonant frequency, the dielectric permittivity of the substrate and its thickness. Therefore a very precise selection of antenna physical parameters is required for its operation. In 1979 an antenna symposium held in New Mexico started an international interest in microstrip antennas. A wide range of papers presented at this conference appeared in a special issue of the IEEE Transactions on Antennas and Propagation [9].

These above mentioned sources provide a broad knowledge of microstrip patch antennas, while the following publications focus more on microstrip patch antenna techniques used in this dissertation .

In 1985, a new feed technique involving a microstrip line electromagnetically coupled to a patch conductor through an electrically small ground plane aperture was proposed by Pozar [10]. The publications that came after this were about the theory of this feeding technique was given in [11], [12], [13], and [14]. Applications of aperture-coupled microstrip patch antennas are presented in [15] and [16]. Pozar [10] illustrates the history, operation, development, and applications of aperture-coupled MSA. Some of the developments related to aperture coupled microstrip antennas are listed below:

(a) Independent selection of antenna and feed substrate materials.

(b) Many possible variations in patch shape, aperture shape, feed line type, etc.

(c) Increased substrate space for antenna elements and feed lines.

(d) Theoretically zero cross polarization in principle planes.

(e) Demonstrated impedance bandwidths ranging from 5% to 50%.

However these features apply to a single band MSA using aperture-coupled feeding techinque. Several broad-banding techniques for microstrip antennas are widely known, the best among them use stacked [15] or parasitic patches [16]. The analysis process of multilayer microstrip antennas is complex and time consuming [17]. Design of dual- and multi-band microstrip antennas even with narrow bandwidths is challenging [18]. Microstrip patch antenna with U-slot was mainly used for bandwidth enhancement [19]. However, further researches revealed that wideband characteristic can be modified to multiband characteristic by intelligent placement of U-slot, thereby perturbing the surface current flow in the patch [20-21]. Also H slot in the patch can also be used to support triple band operation. The improvement in bandwidth in aperture-coupled MSA is primarily a result of the additional degrees of freedom offered by the stub length and coupling aperture size in aperture-coupled antenna.

However if an aperture-coupled antenna is supposed to operate at multiband the coupling aperture slot and patch is supposed of different geometry i.e. U slot as it attributes to increase in bandwidth and allowing multiband operation of the antenna at the same time.

PPDR a matter of state safety is focusing on development of efficient Wireless Communication System for Emergency management and Disaster Relief [3-4]. In an emergency situation communications systems with capability to support services beyond simple voice communications can prove to be life saving for the public safety personnel and civilians alike. Different MSA is reported to support various heterogeneous services that operate on portable devices [22-27]. Results in terms of antenna parameters (chapter4) are found in accordance with the application but none of them has attributed any work in the field of PPDR or emergency management system.

As for PPDR system, an antenna is required to operate at public safety band. As per IND73 of the National Frequency Allocation Table (NFAP-2008) in India, certain frequencies have been allocated in the following bands for public protection and disaster relief (PPDR) communications:

Table 1 National Frequency Allocation Table

380-400 MHz
406.1-430 MHz
440-470 MHz
746-806 MHz
806-824 MHz
851-869 MHz
4940-4990MHz
5850-5925 MHz

The narrowband nature of these radios limits them to two-way voice communications with no additional support for high-bandwidth transmission requirements. The only way to improve the capacity of these public safety networks is to make more spectrum available for such services in the public safety bands [4]. This can be done with the help of using a triple band MSA aperture-coupled antenna operating at public safety band and at the same time having different spectrum for high bandwidth transmission.

The need for wireless broadband communications has increased exponentially in recent years needing quality of service, handover, security, and increased throughput. The main aim of this dissertation is a microstrip patch antenna operating at 3.6 GHz, 5.2 GHz and 5.8 GHz thus allowing high speed networking services for multimedia communication and use of public safety band i.e. 5850-5925 MHz.

The aperture coupled microstrip antenna allows for the separation of the radiating element microstrip patch and feed line and this provides shielding of an antenna from spurious feed radiation. The proposed triple band antenna provides triple band characteristics without any stacking and provides moderate values of 10 dB bandwidth.

1.3PROBLEM STATEMENT

As we have discussed in literature survey, that many researchers have reported the different performance metric based in accordance with the application. The dissertation proceeds with following:

- Design and simulation of the single band MSA covering the public safety band, using aperture-coupled feeding technique using coupling aperture of U shape.
- Design and simulation of dual band MSA using U slot on radiating patch for WLAN applications using aperture-coupled feeding technique.
- Design of triple band MSA antennas using another U slot in the same patch operating at 3.6 GHz,5.2 GHz and 5.8 GHz.
- Comparison of simulated results of the antenna parameters like return loss, smith chart, BW, VSWR etc using

1.4 MOTIVATION

Stacked MSA configuration can be used to achieve dual or multiple frequency operation. It is clear that stacking microstrip patches result in an increased impedance bandwidth over a single layer radiator. This dissertation addresses the procedure to design a single, dual and triple band aperture-coupled MSA.

2611 attacks in Mumbai, Northern Indian flood, and J& K flood had exposed the urgent need for technology upgrades and changes in policy for emergency communications systems in India. As after the 911 attacks in the United States of America, a series of laws have been passed in the USA to upgrade the existing public safety services. Several independent bodies (including government and private) have been set up for this motto, which have been entrusted with the ability to work along with the FCC (Electronic Communications Committee) to develop the policy and technical framework required for these next generation public safety broadband services [3]. In an emergency scenario an infrastructure is required where broadband antenna is required to support high speed communication along with the public safety band. Microstrip antenna is very economical and easily camouflaged inside packages, making them the best suited for consumer applications. A broad-band microstrip antenna would prove very useful in PPDR system to support services beyond simple voice communications (high quality images and videos). Different broadband antennas are proposed till date and each uses different feeding mechanism and a few discusses integration of broadband services and public safety band. It is spurious feed radiation that extracts power from the total available for direct radiation. Aperture coupled microstrip antenna is one that allows for the separation of the radiating element (patch) and feed network with a ground conductive layer and this provides shielding from spurious feed radiation. Narrow bandwidth and low gain are major disadvantages that limit bandwidth of MSA.

The dissertation describes the theory, and discusses the performance of the aperture-coupled microstrip patch antenna using the bandwidth enhancement techniques. The aperture coupled feeding mechanism is used in this configuration of microstrip patch antenna in order to improve the bandwidth performance, gain, and shielding against the spurious feed radiation for the WiMAX and public safety band.

It is hoped that this work will add more information to the growing research literature in the area of broadband PPDR MSA.

1.5 ORGANIZATION OF THE DISSERTATION

This dissertation is organized as follows.

Chapter 2 introduces the main ideas and PPDR and Microstrip Patch Antenna.

Chapter 3 discusses various methods of analysis of MSA.

Chapter 4 discusses the antenna parameters.

Chapter 5 Discusses the aperture coupled MSA.

Chapters 2-5 are primarily a collection of other’s work. Chapters 6-7 represent the author’s original research for this dissertation.

Chapter 6 deals with a specific problem in a PPDR wireless communication system, namely high bandwidth requirements in a MSA along with public safety band. A problem is derived whose solution yields an aperture coupled antenna structure i.e. single band, dual band and triple band. Optimal geometries are then presented for the triple band MSA made up of two U slot in the patch and a U slot aperture with microstrip transmission line model.

Chapter 7 summarizes the important results and presents conclusions based on the solutions. Finally, future problems of interest are discussed.

CHAPTER 2

2.1 INTRODUCTION TO PPDR

2.1.1 Emergency Service or Public Safety Agency

For the purpose of this dissertation the following definition has been found to be appropriate

A service or agency, recognized as such by the Member State, that provides immediate and rapid assistance in situations where there is a direct risk to life or limb, individual or public health or safety, to private or public property, or the environment but not necessarily limited to these situations [28].

Public Protection (PP) Radio Communications:

Radio communications used by responsible agencies and organizations dealing with maintenance of law and order, protection of life and property, and emergency situations [28].

Disaster Relief (DR) Radio Communications:

Radio communications used by agencies and organizations dealing with a serious disruption of the functioning of society, posing a significant, widespread threat to human life, health, property or the environment, whether caused by accident, nature or human activity, and whether developing suddenly or as a result of complex, long-term processes [28].

As the term PPDR is a combination of public protection and disaster relief and illustrated with following figure 2.1. As the situation can be mission critical and non mission critical. On the bases of this public safety operation has been identified as PP1, PP2, and DR.

Day-to-day operations (PP1)

Day-to-day operations are those routine operations that PPDR agencies conduct within their jurisdiction. Typically, these operations are within state borders. Most PP spectrum and infrastructure requirements are already examined and defined.

These operations insure primarily voice and messaging communications which can be fulfilled by narrowband and wideband communications.

Large emergency and/or public events (PP2)

Large emergencies and/or public events are those that PP and potentially DR (1.1.3) agencies are required to respond in a particular area of their jurisdiction. However they are still required to perform their routine operations elsewhere within their jurisdiction. The size and nature of the event may require additional PPDR resources from adjacent jurisdictions including neighboring agencies, or international organizations.

A large earthquake where damage depends upon magnitude of Richter scale may involve outside the jurisdiction of a state, or a large forest fire is examples of a large emergency under this scenario.

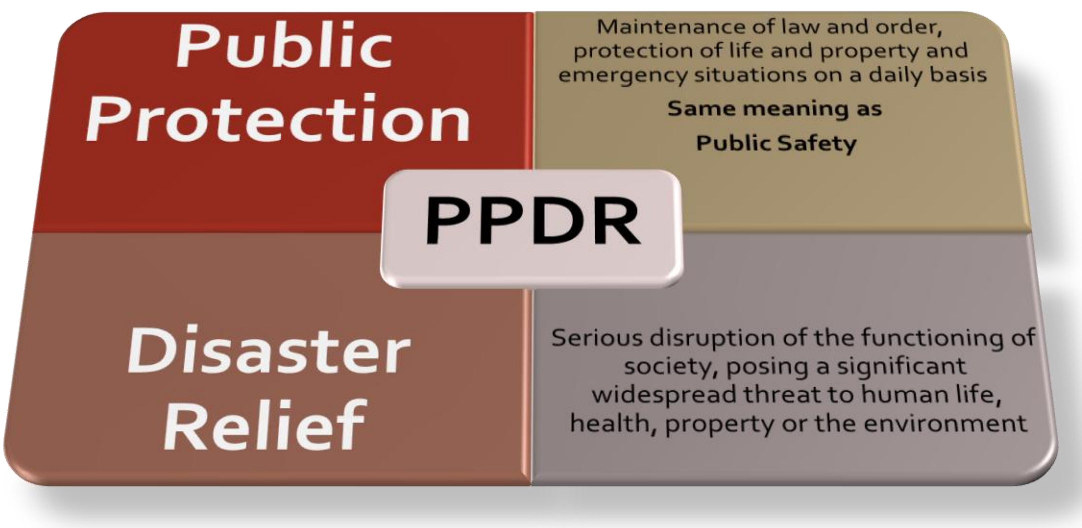


Figure 2.1: Illustration of PPDR [28]

Disaster Relief (DR) operations

Disasters can be caused by either natural or human activity. For example, natural disasters include an earthquake, major tropical storm, an avalanche, floods, etc. Examples of disasters caused by human activity include large-scale criminal or terrorist incidences or situations of armed conflict between the countries. These require efficient and rapid deployment of the networks. Applications are used temporarily by emergency services in all aspects of disaster situations, including disaster prevention. For instance, they provide simultaneous hot spot type of robust communications, video or robotic data information, telemetry parameters, critical data base queries, location information exchange and other heavy data communications [3].

Furthermore, interoperability of communication infrastructure is used to insure joint operations.

New requirements for PPDR Spectrum

Current PPDR applications are mostly narrowband supporting voice and low data-rate applications, typically in channel bandwidths of 25 KHz, 12.5 KHz or 10 KHz. But PPDR in any misfortune mostly requires broadband applications that enable an entirely new level of functionality with additional capacity to support higher resolution images and higher speed data. Therefore broadband radiating structure is required to support PPDR requirements.

However new technology for PPDR includes TETRA (TErrestrial Trunked RAdio).

TETRA was specifically designed to meet the requirements of Public Mobile Radio (PMR), “Walkie-Talkie”. It has a large number of features designed for PPDR as [29]:

- Direct push-to-talk (PPT), to groups and with priority setting
- Centralized call control, for priority and queuing
- Direct mode, portable to portable without central radio coverage (DMO)
- Relay mode, one portable can use another mobile device to link to the central radio
- Use of one or several timeslots for (low speed) data
- Voice encryption, different algorithms available

The same was first implementation in 1997 and from then a number of companies have come and gone e.g. Nokia invested brutally in both networks and handhelds from the start. But In 2006, they sold their complete TETRA division to EADS (European Defense & Space). This makes EADS a competitive leader with Motorola but later is still the global leader [29].

P25 is also a solution for public safety. The most attractive feature of P25 is that even in the loudest environments P25 radios transmit crystal-clear audio with virtually no distortion [30].

2.2 Antenna as a Vital Part of the Wireless Communication System

It is well known fact that an antenna is a vital part of the wireless communication system. Antennas transmit or receive electromagnetic waves by converting electromagnetic radiation into electric current or vice versa figure 2.2 .But in high-performance aircraft, spacecraft, satellite, and missile applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints parameters, low-profile antennas may be required and MSA is quite suitable in that case [35].

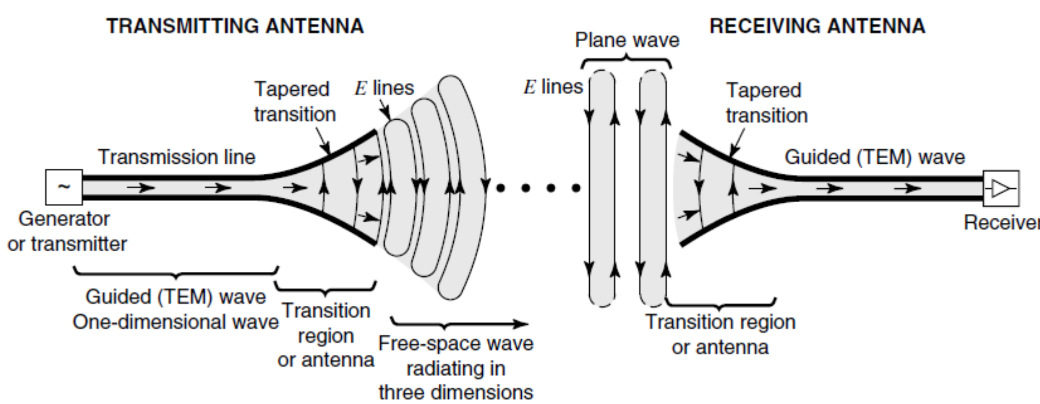


Figure 2.2: Basic operation of a general antenna [33]

The antenna cannot be integrated at the end of the design phase. Successful integration of an antenna into a wireless device depends on the understanding that the entire device is part of the antenna [31].

2.3 ANTENNA PARAMETERS

Regardless of the type and configuration of the antenna, performance can be characterized by the following metrics:

- RL (Return Loss)
- Smith Chart
- VSWR
- Directivity
- Gain
- Radiation Pattern
- Polarization

Return Loss

Return loss the loss of power in signal returned or reflected by the discontinuity. The discontinuity can be mismatch with the terminating load or with a device inserted in the line.

As already known, waves are reflected leading to the formation of standing waves when the transmitter and antenna impedance do not match [18].

The RL is defined as

$$RL = -20 \log10|\acute{\Gamma}| \quad (2.1)$$

$$RL= -20 \log10|Z_1+Z_2/Z1-Z_2| \quad (2.2)$$

Here

$\acute{\Gamma}$ is the reflection coefficient

Z_1,Z_2 are the impedance of the source and the antenna

In practical applications, the applicable VSWR of 2 is acceptable corresponds to an RL of 9.5 dB or 11% power reflection [31].

Smith Chart

The Smith Chart, invented by Phillip H. Smith (1905-1987), is a monogram specializing in RF engineering to assist in solving problems with transmission lines and matching circuits. As being a transducer between the characteristic impedance of the radio system (nominally 50 ohms) and the impedance of free space. The Smith Chart is plotted on the complex reflection coefficient plane in 2-D and is scaled in normalized impedance or normalized admittance or combination of both is used sometimes.

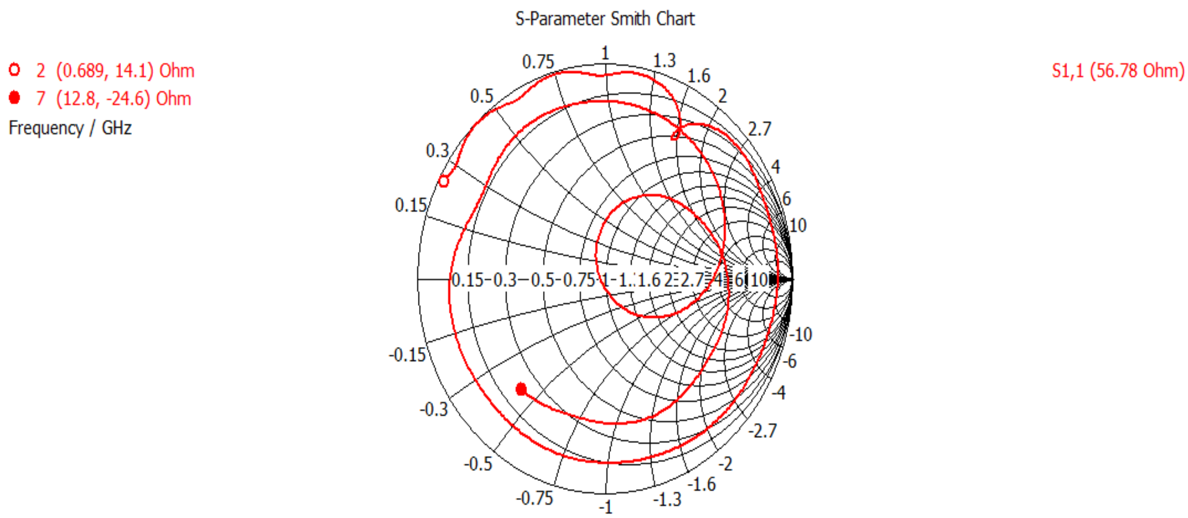


Figure 2.3: Smith Chart

VSWR

When a transmitter section is connected to an antenna by a feed line, the impedance of the antenna and feed line must match exactly for maximum energy transfer. When an antenna and feed line do not have matching impedances, some portion of the electrical energy cannot be transferred to the antenna. As there exists two waveforms ie current and voltage having forward and reflected wave. It is the interference of these reflected waves with forward waves which causes standing wave patterns.

If

$$Z_s = Z_L^*$$

Where

Z_s = Impedance of the source

Z_L^* = Impedance of the load

Matching the impedance of the antenna to the impedance of the feed line is typically done using an antenna tuner.

Return Loss (S11) and VSWR Relationship is described as

Table 2 VSWR comparison table [32]

S11 (dB)	VSWR	Reflection Loss (dB)	Comment
-6.0	3:1	1.2	Marginal
-9.5	2:1	0.5	Acceptable (and typical Antenna Specification)
-15.0	1.4:1	0.15	Good
-20.0	1.2:1	0.04	Very Good

Directivity

The directivity of an antenna is equal to the ratio of the maximum power density $P(\theta, \varphi)max$ (watts/m2) to its average value over a sphere as observed in the far field of an antenna[31]. Thus,

$$D = \frac{P(\theta, \emptyset)max}{P(\theta, \emptyset)avg}$$

Also above equation can be written as

$$D = U / Uo = 4\Pi U / P_{rad}$$

Where,

U=Radiation intensity (W/unit solid angle)

U0 = Radiation intensity of isotropic source (W/unit solid angle)

P_{rad} = Total radiated power (W)

Gain

Gain can be measured by comparing the maximum power density of the Antenna under test (AUT) with a reference antenna of known gain, such as a short dipole [31]. Thus,

$$G = \frac{\text{Pmax(AUT)}}{\text{Pmax (Ref. ant.)}} * \text{G(Ref. ant.)}$$

Radiation Pattern

The radiation pattern is defined as "a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates" [6].

The equation for power is given as

$$P = \frac{1}{2} Re \iint (E1 * H2. ds) \qquad (2.3)$$

$$P = \frac{1}{2\text{no}} \iint (|\text{E}\theta|^2 * |\text{E}\theta|^2 . r^2 \sin\theta \, . d\theta \, d\phi) \qquad (2.4)$$

Above equation in (2.3, (2.4) represents the radiated power from the antenna. It is well know that for a MSA the electric field E within the patch is normal to the patch and the ground.

plane, and the magnetic field H is parallel to the strip edge. Polarization of a rectangular MSA for the dominant mode is linear and directed along the patch dimensions.

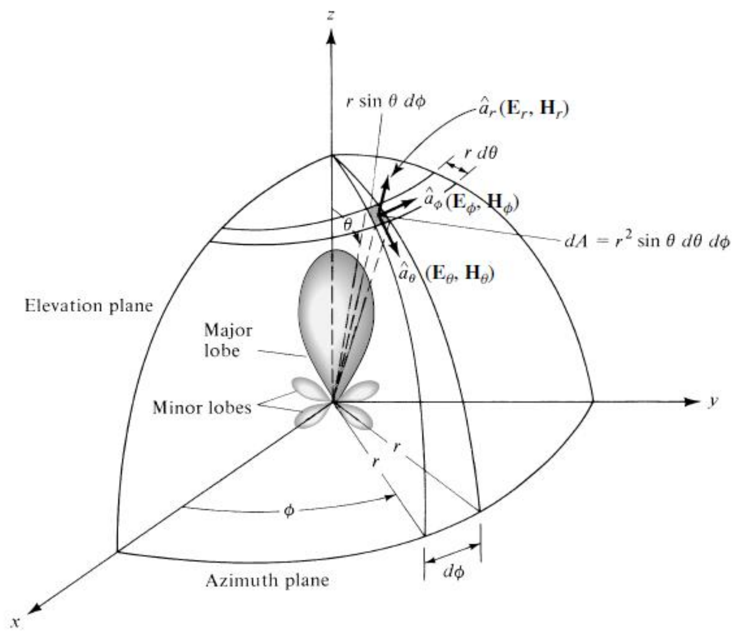


Figure 2.4: Radiation pattern of an antenna [33]

Polarization

It is defined as E field orientation & the possible planer components of the E field the basic transverse nature of EM wave.

Polarization can be classified as linear, circular, and elliptical. In linear polarization the antenna radiates power in the plane of propagation, only one plane. The antenna is said to be vertically linear polarized when the electric field is perpendicular to the earth's surface, and horizontally linear polarized when the electric field is parallel to the earth's surface [36].

Circular polarization antenna radiates power in all planes in the direction of propagation (vertical, horizontal, and between them).
The electromagnetic wave radiated by an antenna has an electric field E with two components E_x and E_y, where

$$\mathrm{Ex} = |Ex| \cos(wt - \beta z) \tag{2.5}$$

$Ey = |Ey|\cos(wt - \beta z + \phi)$ (2.6)

Where

Ex= Amplitude of the field components in the directions of x

Ey= Amplitude of the field components in the directions of y

Ex and Ey describes the nature of polarization.

If,

Ex=Ey=0

The wave is said to be linearly polarized.

If,

Ex=Ey ≠0

The wave is said to be circularly polarized.

And if

Ex≠Ey≠0

The wave is said to be elliptically polarized.

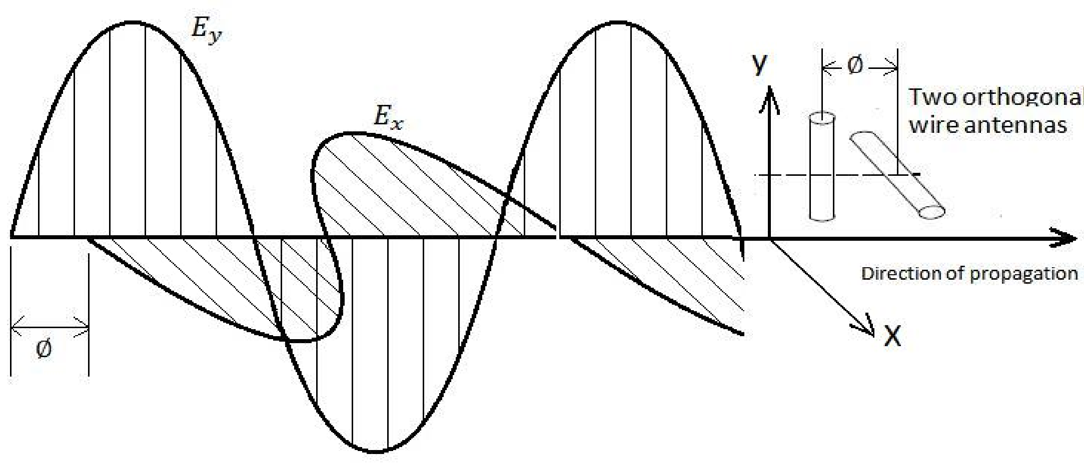


Figure 2.5: Polarization of electromagnetic wave [33]

Impedance Matching

According to the theory of maximum power transfer theorem for the transfer of maximum power from a source with fixed internal impedance to the load, the impedance of the load must be the same of the source.

i.e. $Z_s = Z_L^*$

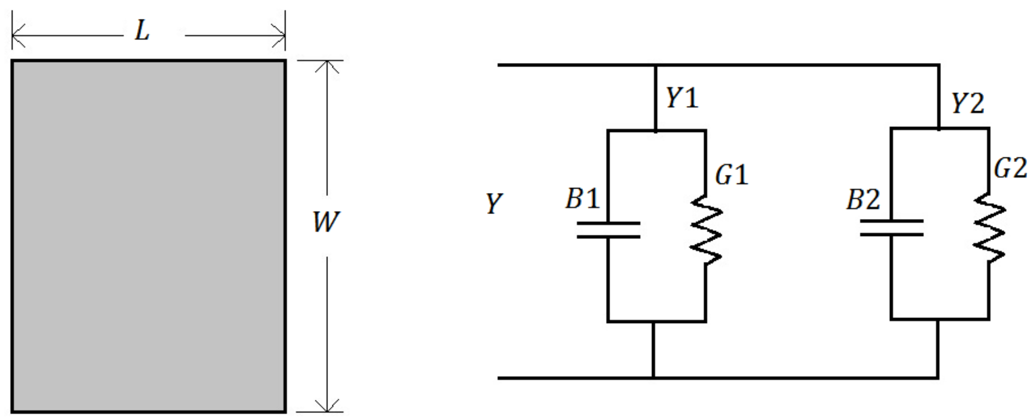


Figure 2.6: Rectangular patch and its transmission model equivalent from [6]

Where

Z_s = Impedance of the source

Z_L = Impedance of the load

C=conductance

B= susceptance

Here

$$Y = \frac{1}{\mathrm{ZL}} = \mathrm{G} + \mathrm{j}\beta \qquad (2.7)$$

From [35],we have

$Y_1 = Y_2$

∴ B1=B2 and G1=G2

A general expression for the conductance G1 is given by [6]

$$G1=\frac{2Prad}{|V0|^2}$$

Where,

Prad is the radiation power

V_o is the voltage across the slot.

$$P_{rad}=\frac{|V0|^2}{2\pi no}\int_0^{\pi}[\sin(\frac{\frac{Ko\ \omega}{2}Cos\ (\theta)}{Cos\ (\theta)})]^2\ Cos(\theta)r^2 d\theta$$

Putting above equation in 1,we have

$$G1=\frac{1}{120\pi}\int_0^{\pi}[\sin(\frac{\frac{Ko\ \omega}{2}Cos\ (\theta)}{Cos\ (\theta)})]^2\ Cos(\theta)r^2 d\theta$$

As

$Z_s=R_s+jX_j=Z_L^*=R_L-jX_L$

$Z_s=\frac{1}{Ys}=R_s=\frac{1}{2G1}$

According to C. Balanis [6]

$R_{in}=\frac{1}{2[G1\pm G12]}$

Where,

(+) sign is used for modes with odd or antisymmetric resonant voltage distribution beneath the patch and between the slots and

(-) sign is used for modes with even or symmetric resonant voltage distribution beneath the patch and between the slots

$$G1=\frac{1}{|Vo|^2}\iint(E1*H2.ds)$$

Where ,

E1 is the electric field radiated by Y1

and H2 is the magnetic field radiated by Y2

$$G_{12}=\frac{1}{120\pi}\int_0^{\pi}[\sin(\frac{\frac{Ko\ \omega}{2}Cos\ (\theta)}{Cos\ (\theta)})]^2\ j_o(Ko\ LSin\theta)Sin^3\theta d\theta$$

J_o is the Bessel function of the first kind of order zero.

The location of feed point of the patch can be found from the following equation:

$R_{in}=\frac{1}{2[G1\pm G2]}Cos^3(\frac{\pi}{L}yo)$

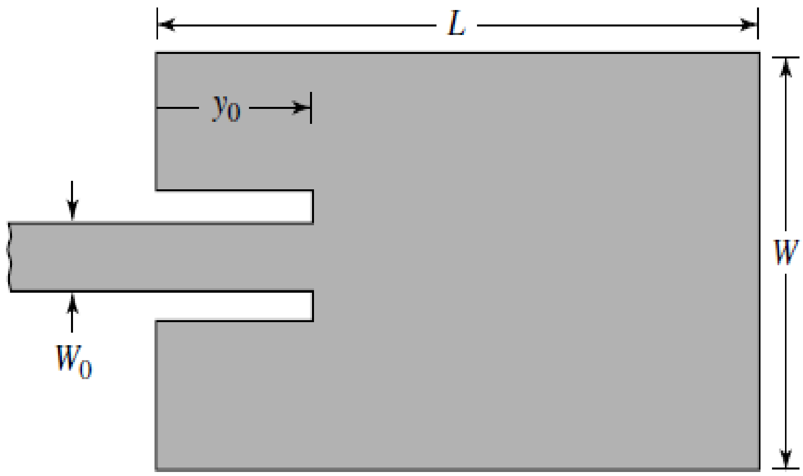


Figure 2.7: Recessed Microstrip-line feed from [6]

Most microwave applications are designed with an input impedance of 50Ω. So matching the antenna to 50Ω is our requirement.

We can begin with representing the patch by a parallel equivalent admittance Y as shown in figure (4.2).

2.4 SUMMARY

The table 1.1 indicates that for different frequency band of PPDR, the wireless application intended for the same must choose one frequency from this table. Also the designed antenna should be low profile, simple and inexpensive and should show the desired performance measures in terms of antenna parameters as explained in the chapter.

Chapter 3

3.1 Introduction to Microstrip Antenna

A microstrip antenna is defined as [34] "An antenna which consists of a thin metallic conductor bonded to a thin grounded dielectric substrate."

The idea of the microstrip antenna was introduced in 1950s but it became popular and took place in various applications in 1970s as due to invention of integrated circuits. Figure 3.1 shows basic structure shows MSA in its simplest configuration.

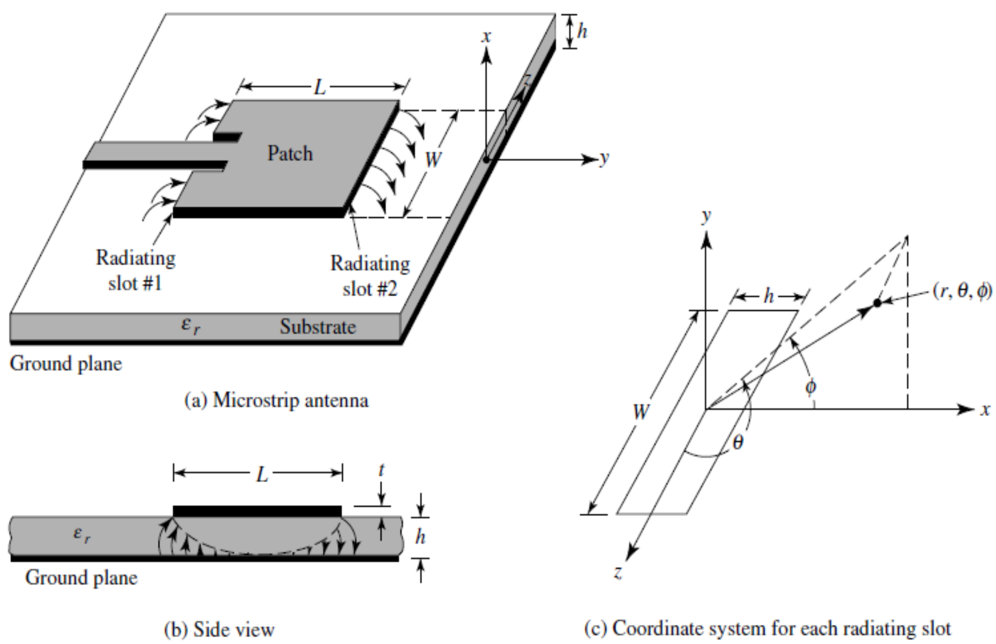


Figure 3.1: Microstrip antenna and coordinate system [6]

MSA consist of a very thin ($t << \lambda 0$, where $\lambda 0$ is the free-space wavelength) metallic strip (patch) placed a small fraction of a wavelength ($h << \lambda 0$, usually $0.003\lambda 0 \leq h \leq 0.05\lambda 0$) above a ground plane [6]. Design of the radiating patch and characteristic of the dielectric substrate determines the behavior of the antenna. The electric field distribution of a rectangular patch excited in its fundamental mode is also indicated in fig 3.1 (b). The most desirable for good antenna performance the values have been suggested as [6]

$\lambda 0/3 \leq L \leq \lambda 0/2$

And

$2 \leq \varepsilon r \leq 12$

3.2 ADVANTAGES AND DRAWBACKS

Advantages of MSA as compared to the conventional antennas are:

- Low profile, conformable to planer & non-planer surfaces
- Simple and inexpensive to manufacture
- Versatile in terms of resonating frequency, polarization, pattern & impedance.
- Feed lines and matching networks can be fabricated simultaneously with the antenna structure.

On the other hand, there are also some limitations compared to the conventional antennas are:

- Sensitivity to environmental factors
- Low power handing
- Spurious feed radiation
- Very narrow frequency bandwidth
- Lower gain (~6 dB)
- Most microstrip antennas radiate into half-space
- Polarization purity is difficult to achieve

3.3 TYPES OF PATCH ANTENNAS

As we know that design of the radiating patches that is, length, width, feed type and characteristic of the dielectric substrate that is, dielectric constant, height of the substrate determine the behavior of the antenna. Therefore the various configuration of antenna patch is given below in figure 4.2 to meet most specific application characteristic.

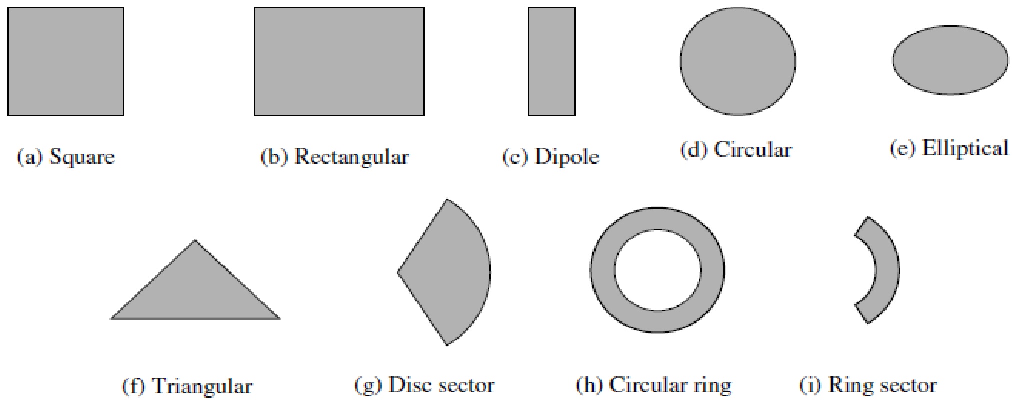


Figure 3.2: Representative shapes of microstrip patch elements [6]

Choosing the substrate is also very important. As various applications considers the temperature, humanity, and other environmental ranges of operating. Thickness of the substrate has a huge effect on the resonant frequency and bandwidth of the antenna. Bandwidth of the microstrip antenna will increase with increasing of substrate thickness but with limits, otherwise the antenna will stop resonating.

3.3.1 Applications of Microstrip Antenna

For many practical designs, the advantages of microstrip antennas far outperform their disadvantages and thus lead to many system applications:

Table 3 Area of application of microstrip patch antenna [10]

Application	Frequency
Global Positioning Satellite	1575 MHz and 1227 MHz
Paging	931-932 MHz
Cellular Phone	824-849 MHz and 869-895 MHz
Personal Communication System	1.85-1.99 GHz and 2.18-2.20 GHz
GSM	890-915 MHz and 935-960 MHz
Wireless Local Area Networks	2.40-2.48 GHz and 5.4 GHz
Cellular Video	28 GHz
Direct Broadcast Satellite	11.7-12.5 GHz
Automatic Toll Collection	905 MHz and 5-6 GHz
Collision Avoidance Radar	60 GHz, 77 GHz, and 94 GHz
Wide Area Computer Networks	60 GHz

3.4 FEEDING METHODS

Many good designs can be discarded because of their bad feeding methods. The most important thing to be considered is the maximum transfer of power between the radiating structure and the feed structure or the impedance matching between them. Basically they can be classified into two categories:

- The contacting
- Non-contacting method.

In contacting the feed line is connected to the patch directly and in non-contacting method patch and the feed line are separated. There are many methods of feeding a microstrip antenna. The most popular methods are:

1. Microstrip feed line
2. Coaxial feed
3. Proximity Coupled
4. Aperture Coupled

3.4.1 Microstrip Line Feed

In this mechanism a conducting strip line is directly connected to the edge of the patch to create a planar structure. The microstrip-line feed is simple to fabricate, easy to match by controlling the inset position and simple to model. However as the substrate thickness increases, surface waves and spurious feed radiation increase, which for practical designs limit the bandwidth (typically 2–5%) [6].

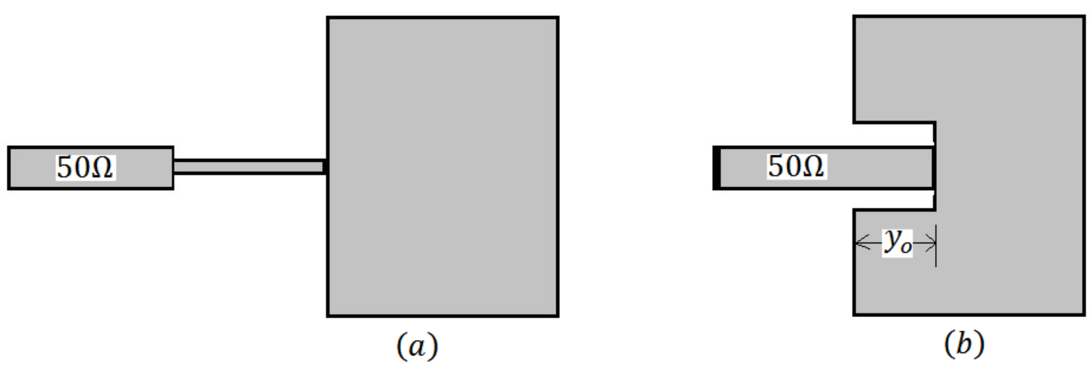


Figure 3.3: Microstrip patch antenna with feed from side

The impedance of the patch is given by [35]

$$Z_a = \frac{90\varepsilon r^2}{(\varepsilon r - 1)} \left(\frac{L}{(W)}\right)^2$$

The characteristic impedance of the transition section should be

$$Z_T = \sqrt{50 + Za}$$

The width of the transition line is calculated from [35]

$$Z_T = \frac{60}{\sqrt{\varepsilon r}} \ln\left(\frac{8d}{(WT)} + \frac{WT}{(4d)}\right)$$

The width of the 50Ω microstrip feed can be found using the equation

$$Z_T = \frac{120\pi}{\sqrt{\varepsilon r}\ (1.393 + \frac{W}{h} + \frac{2}{3}\ln(\frac{W}{h} + 1.444)}$$

Where, $Z_o = 50\Omega$

The length of the strip can be found from as

$$R_{in(x=0)} = Cos^3\left(\frac{\pi}{L} yo\right)$$

The length of the transition line is quarter the wavelength

$$L = \frac{\lambda}{4} = \frac{\lambda_o}{4\sqrt{\varepsilon r}}$$

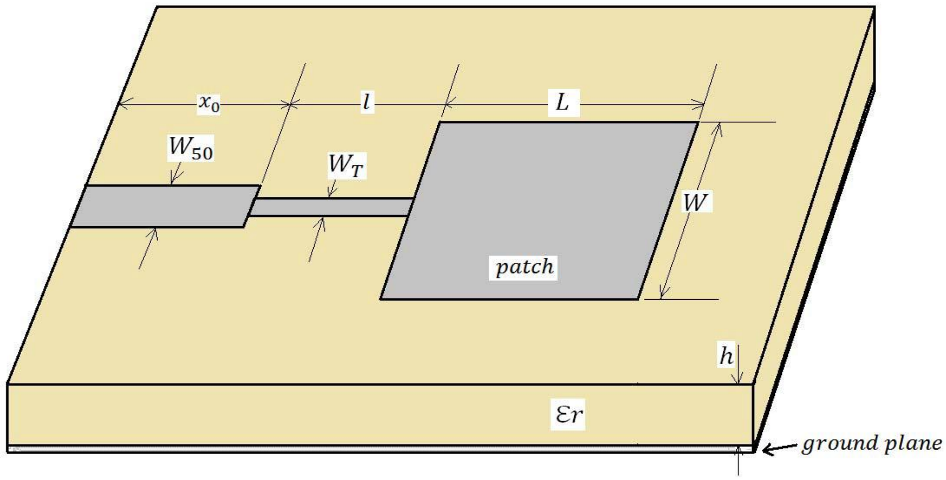


Figure 3.4: Rectangular microstrip patch antenna from [33]

3.4.2 Coaxial Feed

In coaxial-line feeds the inner conductor of the coaxial line is connected to the radiation patch while the outer conductor is connected to the ground plane. The

input impedance depends on the position of the feed. The mechanism also easy to fabricate and match, and it has low spurious radiation.

Let

h= thickness of substrates

if h > 0.02λ0

Then, this feed results in narrow bandwidth and it is more difficult to model

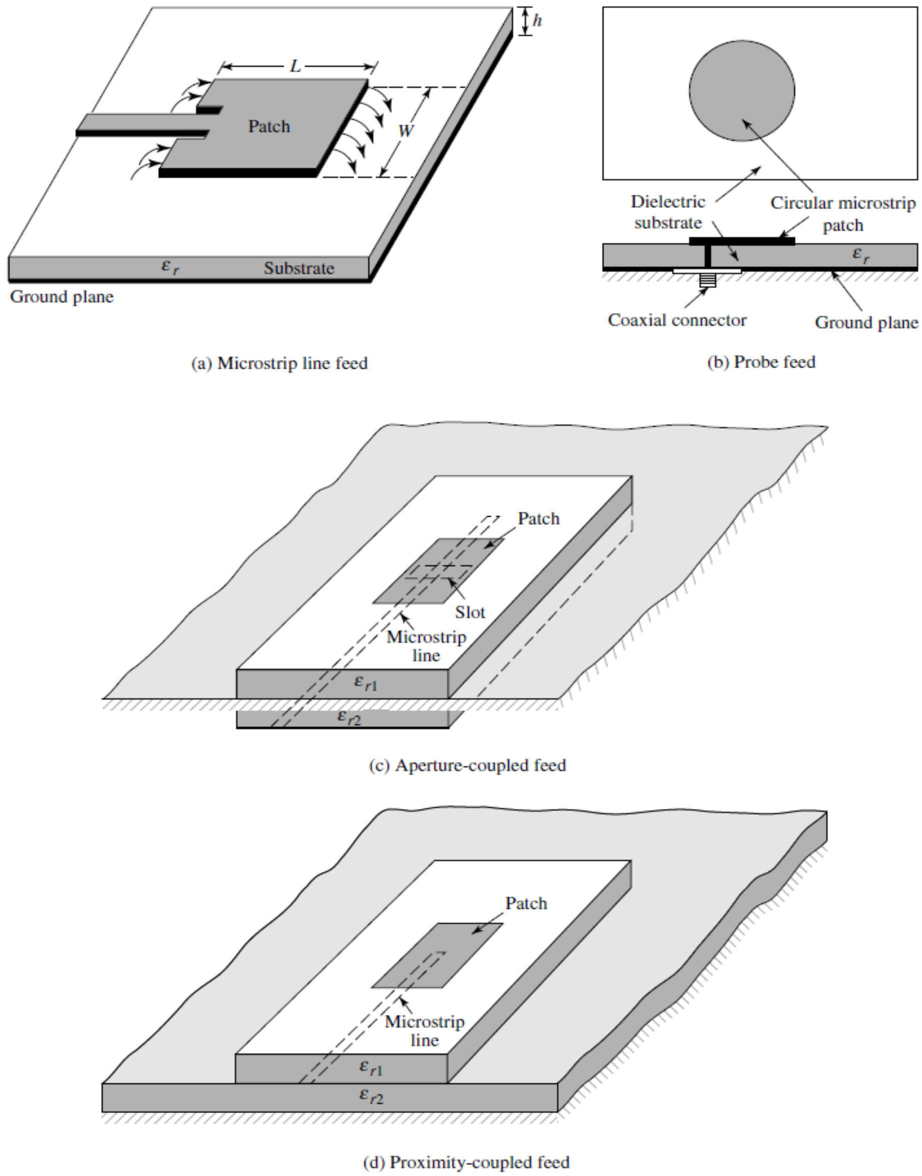


Figure 3.5: Typical feeds for microstrip antennas. From [35]

3.4.3 Proximity Coupling

This is also known as "electromagnetically coupled microstrip feed". There are two substrate in proximity coupling having dielectric constant$\in r1, \in r2$. The patch will be on the top layer, the ground plane in the bottom layer and a microstrip line is connected to the source and lying between the two substrates as shown in the figure (2.5) d.

The advantage of using this feeding technique is elimination of spurious feed radiation and high bandwidth due to overall increase in the thickness of the microstrip patch antenna.By controlling width-to-line ratio of patch the Impedance matching is achieved.The main disadvantage of this lies in difficulty in fabrication due
to the need of proper alignment between the two substrates [35].

3.4.4 Aperture Coupling

The aperture coupled feed exhibits reduced transmission line radiation and enhanced antenna radiation relative to microstrip and probe fed configurations. This structure avoids a direct connection between the patch and the feed line is the aperture. Aperture is cut in the ground plane which is sandwiched between two dielectric substrate of same or different dielectric constant depending upon the requirements. Here the feed consists of an open-ended microstrip line that is located below the second dielectric slab or the bottom layer. The microstrip patch is on the top layer as usual.

The aperture coupling is most difficult of Figure 14.3(c) of all four feeding technique to fabricate and it also has narrow bandwidth.

3.5 SURFACE WAVES

The sole purpose of an antenna is to radiate energy into space in from of EM waves. These are waves that move towards the free space the power of a EM wave decreases with distance r as$1/r^2$.

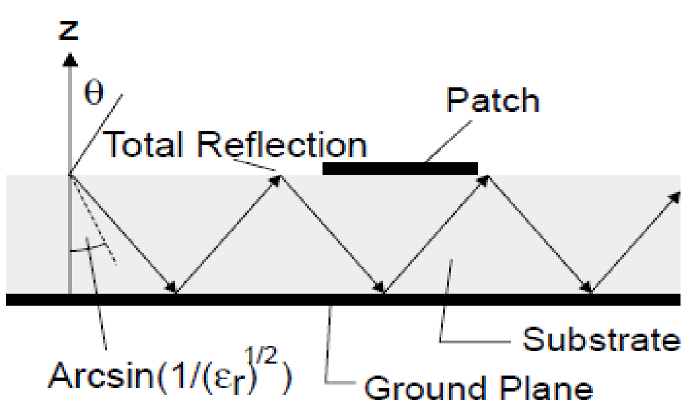


Figure 3.6: Surface waves.

Surface waves exist and propagate within the dielectric substrate, bend at the discontinuities and extract power from the total available for direct radiation. Their source of excitation is a function of the thickness of the substrate. For very thin substrates of a MSA, the losses because of surface waves are very little and can be neglected. However, for thicker substrates they need to be taken into account [35].These waves poses a limitation to the scan of a MSA and the scan angular volume can be extended by eliminating surface waves.

As these waves propagate downwards from the patch into the patch substrate, having an elevation angle ɵ between

$$\frac{\pi}{2} \leq \Theta \leq \pi - arc\sin(\frac{1}{\sqrt{\varepsilon r}})$$

The power of these waves decreases 1/r with distance.

The cutoff frequency fc of these in varios modes is given by [20]

$$f_c = \frac{nc\,1}{4h\sqrt{(\varepsilon rp}-1)}$$

where

n = 0; 1; 2; 3; . . . for the TM0, TE1, TM2,. . . surface modes

Surface waves extract power from the signal energy, thus decreasing the antenna efficiency η, which is defined as

$$\eta = P_r/P_{in} = \frac{Pr}{(Pr+Ps+Pcu+Pdi)} \qquad 3.12$$

Where

P_r=The radiated power from the antenna

P_{in}=The input power to the antenna

P_s=The power consumed by the surface waves

P_{cu}=The power consumed by the copper losses

P_{di}= The power consumed by the dielectric losses

3.6 QUALITY FACTOR, BANDWIDTH, AND EFFICIENCY

There is no complete freedom to independently optimize the quality factor, bandwidth, and efficiency. These are also called figure of merits of an antenna. To achieve an optimum performance a trade off is required between three.

Quality factor is representative of the antenna losses and 3.12 illustrate the various losses of an MSA.

$\frac{1}{Qt} = \frac{1}{Qrad} + \frac{1}{Qc} + \frac{1}{Qd} + \frac{1}{Qsw}$

where

Qt = total quality factor

*Q*rad = quality factor due to radiation(space wave) losses

Qc = quality factor due to conduction (ohmic) losses

Qd = quality factor due to dielectric losses

Qsw = quality factor due to surface waves

The fractional bandwidth of the antenna is inversely proportional to the *Qt* of the antenna, and it is defined by

$\frac{\Delta f}{f0} = \frac{1}{Qt}$

If accounting the matcing in the above formula we have

$$\frac{\Delta f}{f0} = \frac{vswr - 1}{Qt(\sqrt{(vswr)}}$$

For a rectangular microstrip antenna at a constant resonant frequency can be expressed as [35]

BW ∼ volume = area · height = length · width · height

BW$\sim\frac{1}{\sqrt{\varepsilon r}}$

From above equation it is clear that bandwidth is inversely proportional to the square root of the dielectric constant of the substrate.

The radiation efficiency of an antenna is expressed by (2-13), and it is defined as the power radiated over the input power. In terms of quality factor it can be given as:

ecdsw = $\frac{1/Q\text{rad}}{1/Qt}$ = *Qt* /*Q*rad where,

ecdsw= antenna radiation efficiency, which is used to relate the gain, directivity and surface waves.

3.7 SUMMARY

From the discussion it is clear that the various parameters of a MSA in terms length, width, dielectric constant, thickness of the substrate, and slot shape have to be chosen carefully in order to achieve the desire antenna performance. The aperture coupling method is however most difficult to fabricate and have narrow band but posses inherent advantage as the ground plane between the substrates isolates the feed from the radiating element and minimizes interference of spurious radiation for pattern formation.

Chapter 4

4.1 METHODS OF ANALYSIS

There are many methods of analysis for microstrip antennas. The most popular of them is the *transmission-line model.* The transmission-line model is the easiest of all, it gives good physical insight, but is less accurate and it is more difficult to model coupling [35].

There is also another method called cavity mode. If compared to transmission-line model, the cavity model is more accurate but at the same time more complex. However, it also gives good physical insight and is rather difficult to model coupling [35].

4.2 RECTANGULAR PATCH

The rectangular patch is the most widely and often used configuration for the patch. It is very easy to analyze using both the transmission-line and cavity models, which are most accurate for thin substrates [35]. Let us begin with transmission line model.

4.2.1 Transmission Line Model

It is the easiest way to study the microstrip antenna with this model. In this method the transmission line model represents the microstrip patch antenna by two slots. These two slots are separated by a low-impedance transmission line of length .

Basically the transmission-line model represents the microstrip antenna by two slots. These two slots are separated by a low-impedance (Zc) transmission line of length (L).

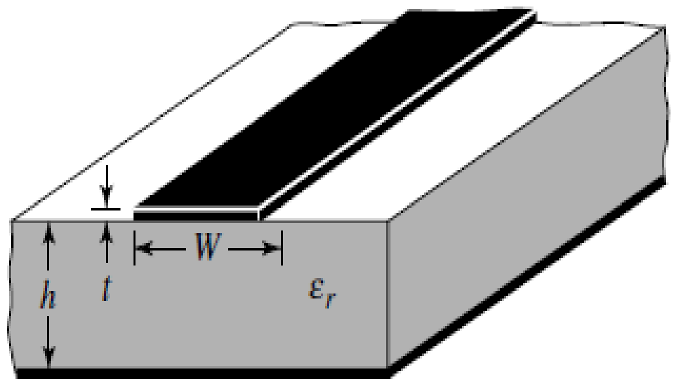
To study the theory of microstrip transmission line model we have two different cases:

1. $W/h < 1$
2. $w/h >>1$ and $\in_r>1$

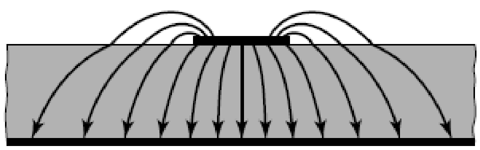
One is discarded as narrow strip line is not what we are interesting with

2nd case gives mathematically a good insight of MSA.

This represents the model as a non-homogeneous line of two dielectrics; typically the substrate and air. As the electric field lines travel inside and in air, therefore an *effective* *dielectric constant* $\in_{reff}$ is introduced to account for fringing and the wave propagation in the line. Fringing is because of finite dimension of the patch and this makes the microstrip line look wider electrically compared to its physical dimensions figure 4.1.



(a) Microstrip line



(b) Electric field lines

Figure 4.1: Microstrip line and its electric field lines, and effective dielectric constant geometry.[35]

Let,

The width W, the length L of the patch, and height h, and the dielectric constant $\in_r$ of the substrate.

Here

$$\in_{reff} = \frac{\in r + 1}{2} + \frac{(\in r - 1)}{2}\left(1 + 12\frac{h}{W}\right)^{-1/2}$$

Effective Length, Resonant Frequency, and Effective Width

MSA dimension greater than its physical dimension is due to fringing.

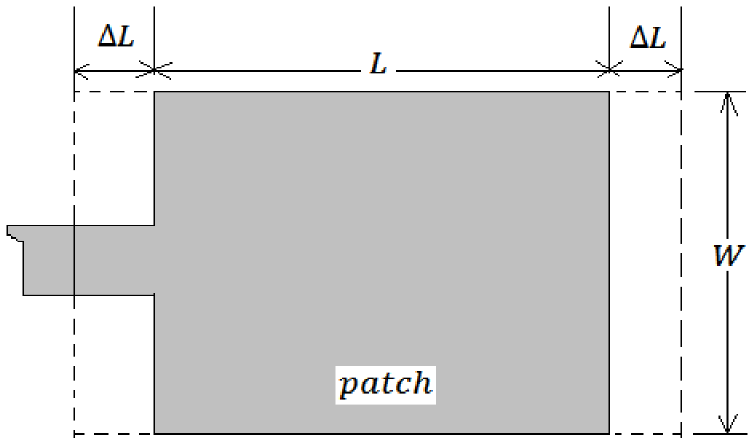


Figure 4.2: Physical and effective lengths of rectangular microstrip patch [35].

$$\frac{\Delta L}{h} = 0.421\frac{(\in r + 0.3)}{(\in r - 0.258)}\frac{(\frac{W}{h} + 0.264)}{(\frac{W}{h} + 0.8)}$$

Since the length is increased by ΔL, therefore effective length is given by

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

For the dominant TM010 mode, the resonant frequency of the microstrip antenna is a function of its length and is given as

$$(f_r)010 = \frac{Ç}{2L\sqrt{\in r}}$$

Where

Ç= velocity of light

If above equation accounts for fringing

$$\therefore (f_{rc})_{010} = \frac{c}{2L_{eff}\sqrt{\epsilon_{eff}}}$$

The width of the patch is given by following formula

$$W = \frac{c}{2f_r}\frac{\sqrt{2}}{\sqrt{(\epsilon_r+1)}}$$

The length of the patch is given by following formula

$$L = \frac{c}{2f_r\sqrt{(\epsilon_{eff}}} - 2\Delta L$$

Following figure shows the variations, as a function of frequency, of the effective dielectric constant of a microstrip line with three different substrates

Calculation of Ground Dimensions (Lg, Wg)

The transmission line model is applicable to infinite ground planes only.

However, for practical considerations, it is essential to have a finite ground plane. It has been shown by that similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery.[18]

Hence, for this design, the ground plane dimensions would be given as:

$$L_g = 6h + L$$

$$W_g = 6h + W$$

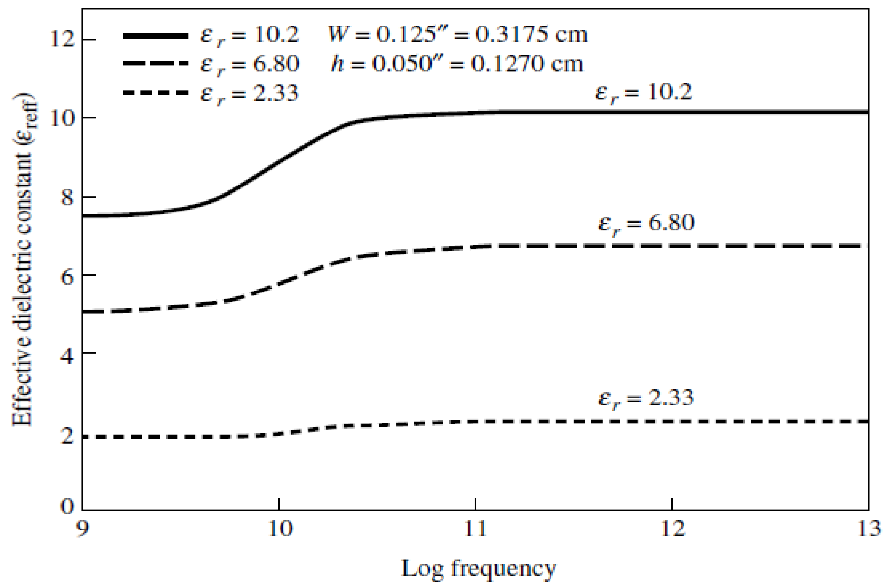


Figure 4.3: Effective dielectric constant versus frequency for typical substrates. From [35]

4.2.2 Cavity Model

This model of analyzing the microstrip antennas is based on the assumption that the region between the microstrip patch and ground plane is a resonance cavity as shown in figure (3.6). This is an accepted model, and it is similar to the perturbation methods which have been very successful in the analysis of waveguides, cavities, and radiators. By treating the bounded region as a cavity

bounded by electric conductors (above and below it) and by magnetic walls (to simulate an open circuit) along the perimeter of the patch [35].

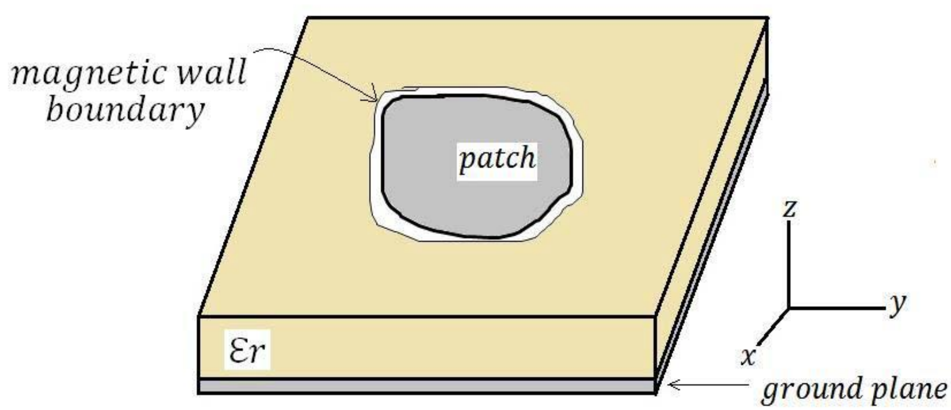


Figure 4.4: Magnetic wall model of a microstrip patch antenna from [36]

There are some assumptions on the bases of which above statements are made:

1. There exist only three field components in the bounded region: E_z component of electric field intensity in the z direction and two components of magnetic field intensity in H_x and H_y direction.

2. As the height of the substrate h is very thin

i.e. $h \ll \lambda$

The field in the inner region does not vary with z-coordinates for all frequencies.

3. The electric current that flows in the microstrip patch has no component normal to the edge of the microstrip patch at any point.

Mechanism of the cavity

When energy is supplied to the microstrip antenna, the charge distribution will be established on the upper and the lower planes of the antenna as shown in figure (ca2). The distribution of the charge is controlled by two mechanisms

1 Attractive

2 Repulsive

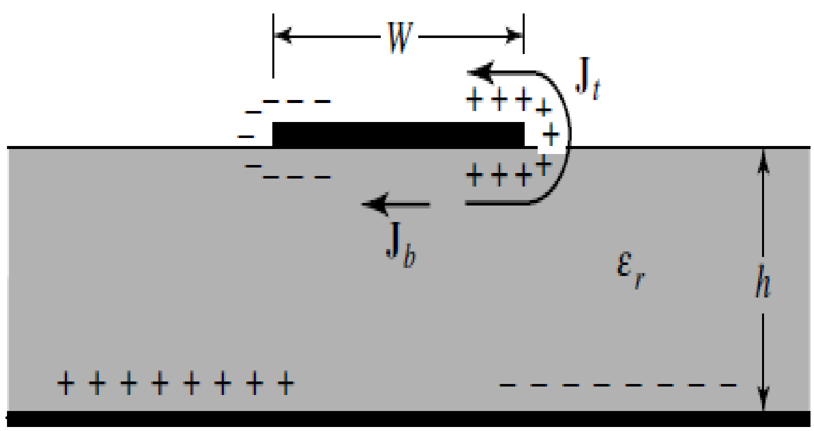


Figure 4.5: Charge distribution and current density creation on microstrip patch. From [35]

The attractive force exists 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 exists between the like charges and this tends to push the charges from the lower surface of the patch, around the edge of the patch to the top of the patch. The current density in this case is J_c as shown in figure (3.7).

As from equation, we have assumed

$$W >> h$$

In this case the attractive mechanism dominates. The charges concentration will within the dielectric below the patch. The current flow around the edge can be discarded as it decreases as the ratio height to width decreases.

This procedure will allow the four side walls to be modeled as perfect magnetic conducting surfaces which ideally would not disturb the magnetic field. This gives good approximation of cavity model and leads us to deal with the side walls as a perfect magnetic conducting wall.

From above assumption, the wave equation we have is as

$$\nabla \times \nabla \times E - k^2\vec{E} = -j\omega\mu_\circ\vec{J}$$

$$\nabla^2 Ez + k^2 Ez = j\omega\mu_\circ\hat{Z}.\vec{J}$$

Where

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

$K = \omega^2\mu_\circ\varepsilon_\circ\epsilon eff$ = wave number

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

Chapter 5

5.1 APERTURE COUPLING

An aperture-coupled design is proposed for microstrip antenna to improve its radiation pattern as well as bandwidth. The aperture which is sandwiched between the two dielectric substrate is usually centered with respect to the patch where the patch has its maximum magnetic field. There is a feed line on the lower substrate and patch as usual on the upper substrate.

The figure 1 in gives the exploded view of this type antenna. The antenna consists of four layers. Two Radiators are microstrip patches and two substrates.

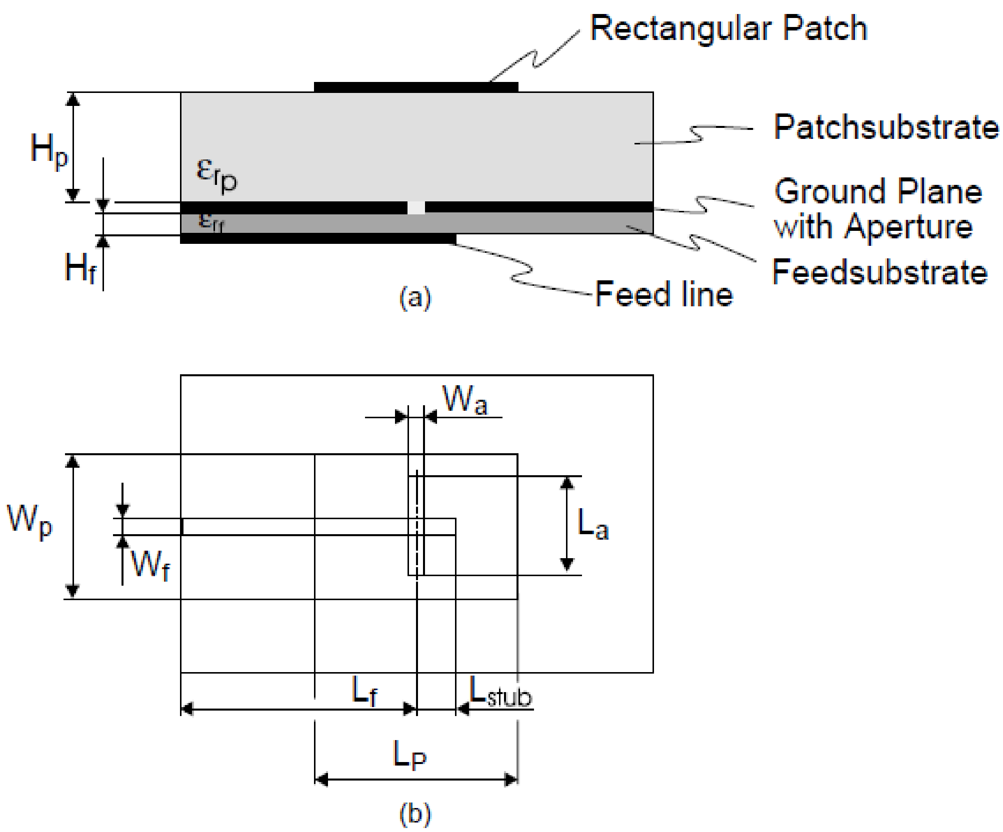


Figure 5.1: Geometry of the aperture-coupled microstrip antenna. (a) Side view. (b) Top view. From [39]

5.2 DESIGN RULES

Since an aperture-coupled antenna is a very complex electromagnetic structure. It uses a wide range of material and dimensional parameters, which affects the performance of the antenna. These are given as:

Antenna Substrate Dielectric Constant:

This affects directly the bandwidth and radiation efficiency of the antenna. The lower the value of permittivity the wider is the impedance bandwidth and also results in reduced surface wave excitation.

Antenna Substrate Thickness:

This affects the bandwidth and coupling level. A substrate which is thicker results in wider bandwidth, but also in less coupling for a given aperture size.

Microstrip Patch Length:

The length of the microstrip patch determines the resonant frequency of the antenna.

Microstrip Patch Width:

The width of the microstrip patch has relationship with the resonant resistance of the antenna. The wider size of the patch gives a lower value of resistance.

.

Feed Substrate Dielectric Constant:

For good antenna performance it must be taken between 2 and 12 [35].

Feed Substrate Thickness:

Less the value of the thickness of the microstrip substrates, less will be the spurious radiation from feed lines. But this results in higher loss. A value between of 0.01l to 0.02l is usually good [10].

Slot Length:

The coupling level is determined by the length of the coupling slot. There are two types of slots

- Resonant
- Non-resonant

If the length of the slot is comparable to the half of the wavelength of the antenna, it is called resonant slot. If it is less, is non-resonant slot.

As the slot length is decreased, there is effect on various parameters

- Input resistance decreases
- Decrease in the coupling between patch and feed line
- Decrease in back radiation level.

The slot must therefore be made no larger than is required for impedance matching.

Slot Width:

The width of the slot affects the coupling level, but to a much less degree than the slot length.

The relation between slot length and width is given by

$L_s/L_{w=}$ 1/10

Where, L_s= slot length

L_w= slot width

Feed Line Width:

It controls the characteristic impedance and the coupling level. According to [10], to a certain degree, thinner feed lines couple more strongly to the slot.

Feed Line Position Relative to Slot:

Maximum coupling takes place, if the feed line is positioned at right angles to the center of the slot. Slanting direction of the feed line from the slot will reduce the coupling.

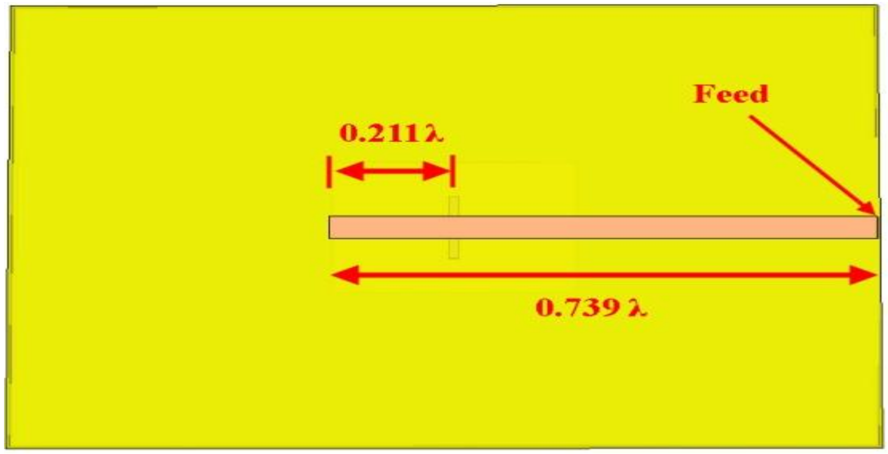


Figure 5.2: Microstrip feed line and nominal dimensions [San Luis Obispo]

Position of the Patch relative to the Slot:

Maximum coupling takes place, if the patch is positioned to the center of the slot, one layer above. For maximum coupling, moving the patch relative to the slot in the H plane direction has very less effect, on the other hand moving the patch relative to the slot in the E-plane direction will decrease the coupling level.

Length of Tuning Stub

As feed line doesn't terminate exactly below the aperture, this excess length is called stub length. It has a remarkable influence on the input impedance of the antenna. It is also used to tune the excess reactance of the slot coupled antenna. The stub is typically slightly less than that of ʎg/4 in length.

Antenna Operation

Figure 2-1 shows the in block diagram of aperture coupled microstrip antenna.

The feed line energizes the structure and creates an electric field in the aperture, which induces surface currents on the patch. The patch edges which are perpendicular to the feed line create fringing fields that radiate into free space.

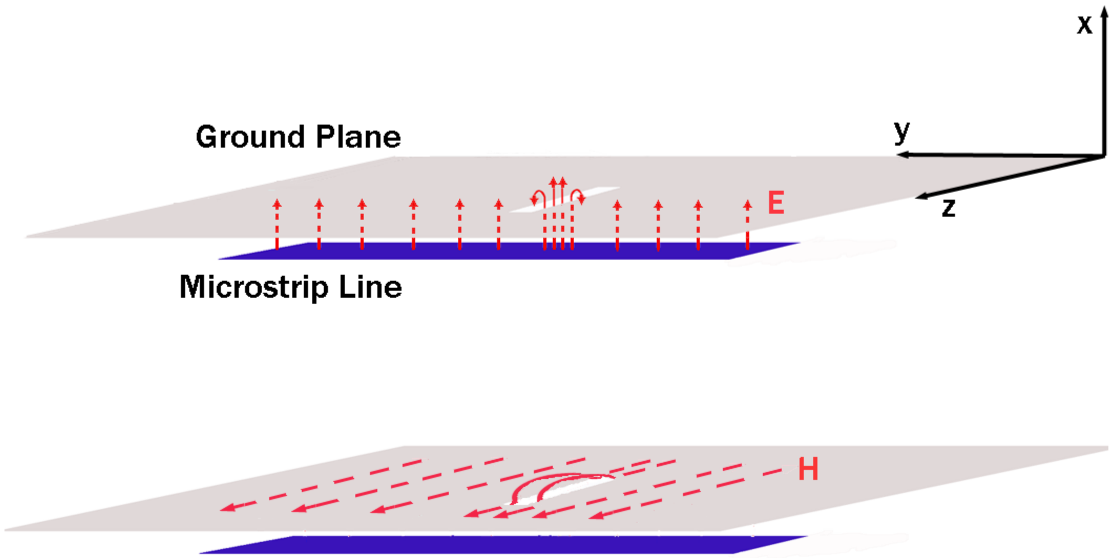


Figure 5.3: Electric and magnetic fields distribution in the feeding network (a) [orested]

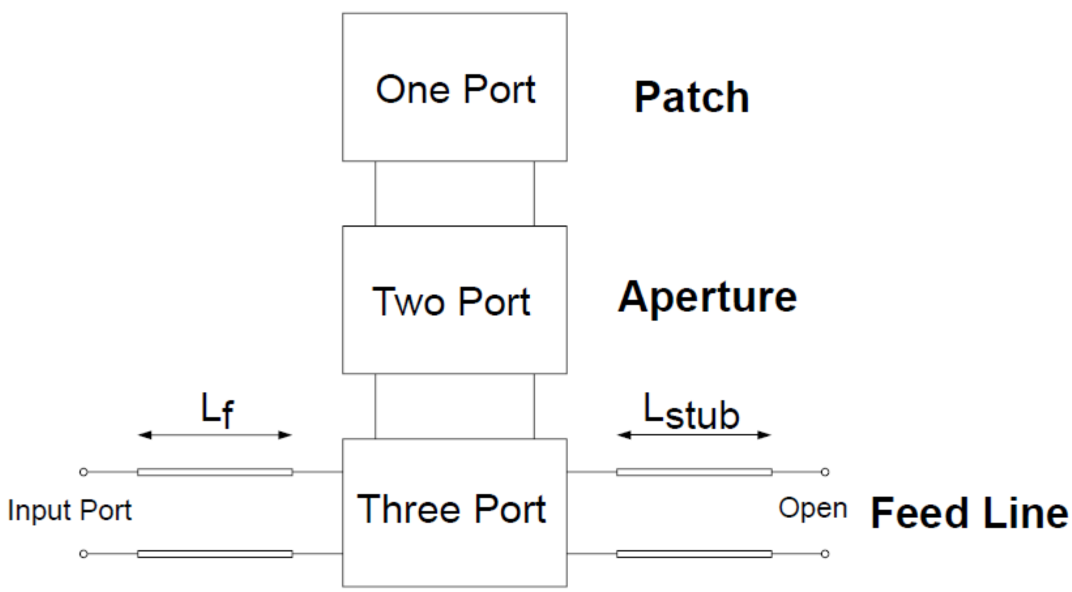


Figure 5.4: Aperture coupled microstrip antenna block diagram [40]

The different layer has been represented with the following diagram.

The feed line, aperture slot and patch have been shown with the following figure

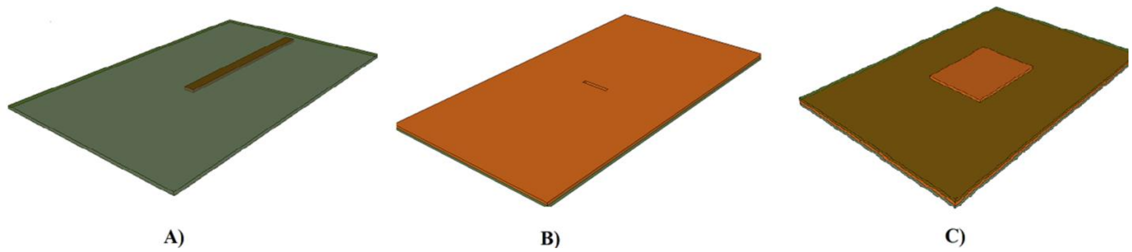


Figure 5.5: A) Conductive microstrip feed (1st layer) underneath feed substrate (2nd layer) B) Slotted ground plane (3rd layer) C) Radiating patch (5th layer) on antenna substrate(4th layer) [40]

The coupling between the feed line and the aperture is viewed as general three port network and the aperture is treated as a two port and the patch is finally viewed as a general one port figure 5.1.

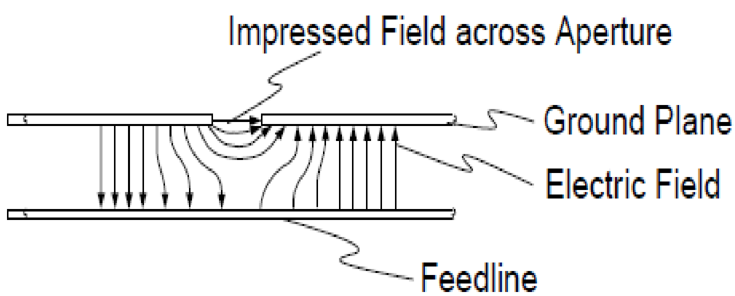


Figure 5.6: Scattering from the aperture.

The nature of the coupling between the feed line and the aperture is done by considering the scattering from the aperture. Figure 2.12 show that the electric field in the aperture is predominantly directed across the aperture plane. The scattering of the aperture is antisymmterical. Although the coupling of the aperture can be modeled by a series of connection, this includes replacing the blocks in figure [] by an electrical elements.

Resonant Frequency

The resonant frequency of the aperture-coupled patch antenna is mainly controlled by the relative permittivity of the patch substrate and the length of the patch. From Equation 2.1 the resonant frequency can be calculated and accounts for the fringing field. But from the equivalent circuit, it can be concluded that the aperture has an influence on the resonant frequency of the antenna. The aperture usually behaves like an inductance and therefore the resonant frequency is shifted downwards.

2.4.3 Coupling

The parameters which influence the coupling factor are:

- Slot length Ls
- Slot width Ws
- Stub length L_{stub}

If we can increase the area of the aperture by manipulating L_s and W_s,thus increasing the coupling. But if we will decrease the area, the patch and the feed line are fully decoupled. So the area cannot be too large even, as then it may start to resonate too. This is a highly unwanted operation because it strongly increases the back radiation level.

Stub length has been discussed already in this chapter.

Chapter 6

6.1 DESIGN OF MICROSTRIP PATCH ANTENNA FOR PPDR USING APERTURE

In this chapter, the procedure for designing a U slot aperture-coupled microstrip patch antenna is explained. The design is simulated using Computer Simulation Technology (CST) Microwave Studio 2010. Finally, the results obtained from the simulations are demonstrated below. Firstly a single band antenna is designed for wireless communication for PPDR at a frequency of 5.8 GHz. The dual band with U slot in ground plane and patch, covering the frequency bands of 3.7GHz and 5.6GHz is designed. Finally the desired triple band aperture- coupled microstrip antenna is designed for high speed communication and PPDR application.

6.1.1 Design of Single Band Aperture Coupled Microstrip Antenna at 5.8875 GHz

The rectangular patch antenna is approximately a one-half wavelength long section of rectangular Microstrip transmission line. The resonant length of the antenna is slightly shorter because of the extended electric "fringing fields" which increases the electrical length of the antenna slightly. [3]

Design Specifications of Single Band

As the antenna has to be designed in such a way that it operates in 5.850 GHZ to 5.925 GHz. A middle value i.e. 5.8875 GHz is chosen to allow the proper operation of working.

Arlon AR 600 having $\epsilon_{r=}$=6 is used for the lower substrate and FR4 (lossy) having $\epsilon_{r=}$=4.3 is used for upper substrate. The value of h is chosen as 2 mm. Matlab code (Appendix) is used to calculate width and length of the patch.

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

•Frequency of operation (f_r): The resonant frequency of the antenna is selected for PPDR operation. The resonant frequency selected for our design is 5.8875 GHz.

•Length of the Patch (L): This is selected to be of equal length and is 15.65 mm.

•Width of the Patch (W): This is selected to be of equal length and is 11.83 mm.

•Length of the Ground (L): This is selected using equation to be of equal length and is 19.03 mm.

•Width of the Ground (W): The is selected to be of equal length and is 22.85 mm

•Dielectric constant of the substrate ($\in_r$)

As we require a low-loss, electrically thin feed substrate (< λ/50) with high dielectric constant ($\in_r > 5$) to maximize guided waves between feed line and ground plane [41].The dielectric material selected for our design has a dielectric constant of 6. A substrate with a high dielectric constant has been selected as it reduces the dimensions of the antenna.

As there are two substrate, so select with relatively low dielectric constant ($\in_{r=}$=4.3) to maximize radiated waves at the patch edges .

•Height of dielectric substrate (h): For the microstrip patch antenna to be used in PPDR system, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate is 2 mm.

•Slot Length along the U axis (W_s): The length of slot along the Us was firstly .148ʎ i.e.7.54 mm but axis was adjusted to be 15.352 mm in order to obtain better results.

•Slot Length along the V axis (L_s): The length of both slots along the V axis was .0164ʎ i.e. .835 mm but adjusted to be 1.67 mm in order to obtain better results.

Length of Tuning Stub

The stub is typically slightly less than that of ʎg/4 = 6.5285 in length. It was adjusted to 2.572 mm.

Feed Width (W_f): The width of microstrip feed line is .739ʎg i.e. 19.29 mm. Hence, the essential parameters for the design are:

Feed Width (L_f): The width of microstrip feed line is .739ʎg i.e. 19.29 mm. But it is taken as 12.515 mm for achieving resonance around 5.8875 GHz.

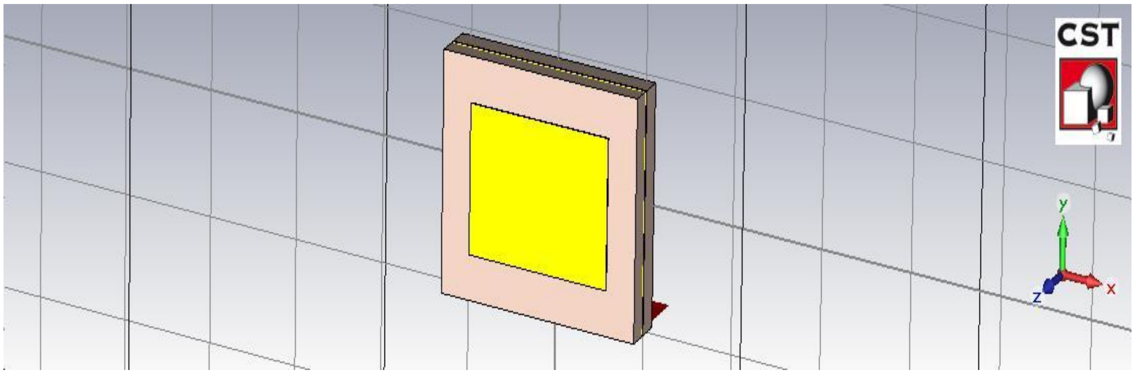


Figure 6.1: Designed structure on CST Microwave Studio

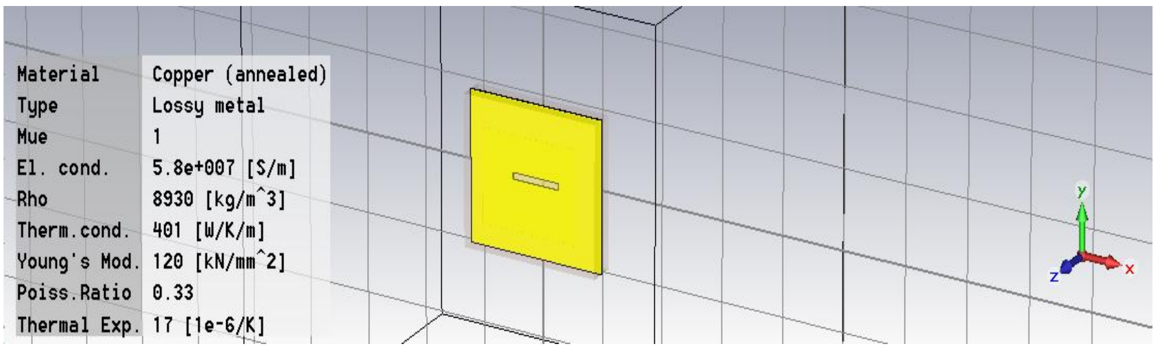


Figure 6.2: Simulation Setup and Result of Single Band Antenna at PPDR (5.850 GHz-5.925 GHz)

Return Loss

Figure 6.3 shows the S11 parameters (return loss) for the proposed antenna resonates at 5.8875 GHz having value of -35.88dB. The bandwidth of the antenna can be said to be those range of frequencies over which the return loss is greater than -10 dB (corresponds to a VSWR of 2). Thus, the bandwidth of aperture coupled antenna can be calculated from return loss versus frequency plot. The bandwidth of the proposed patch antenna is 7.06% GHz. More is the return loss means more of the coupling from the aperture to the patch. If coupling is more than the antenna will have more directivity.

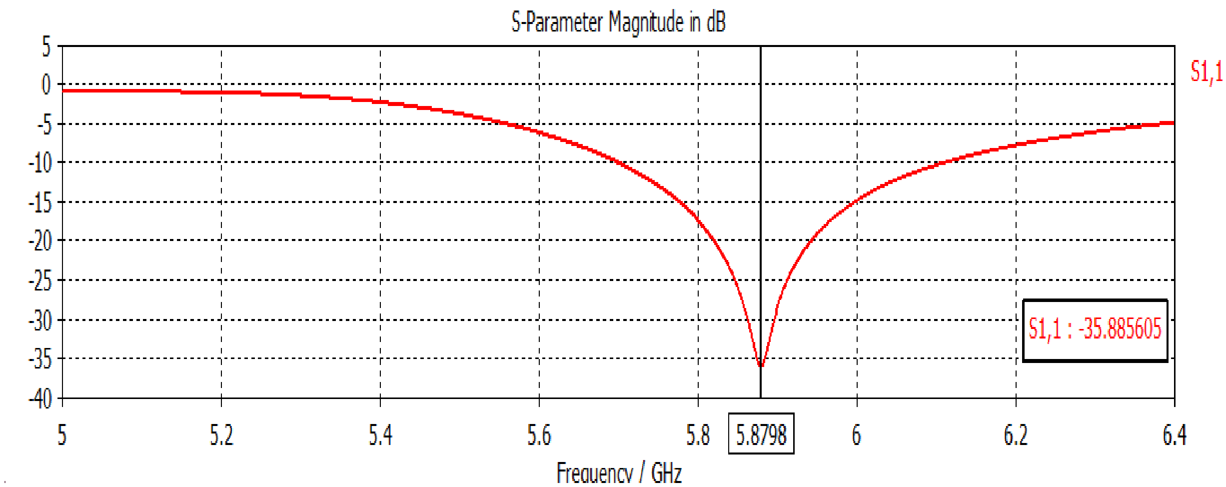


Figure 6.3: Return Loss S11 (in dB) at 5.8798 GHz

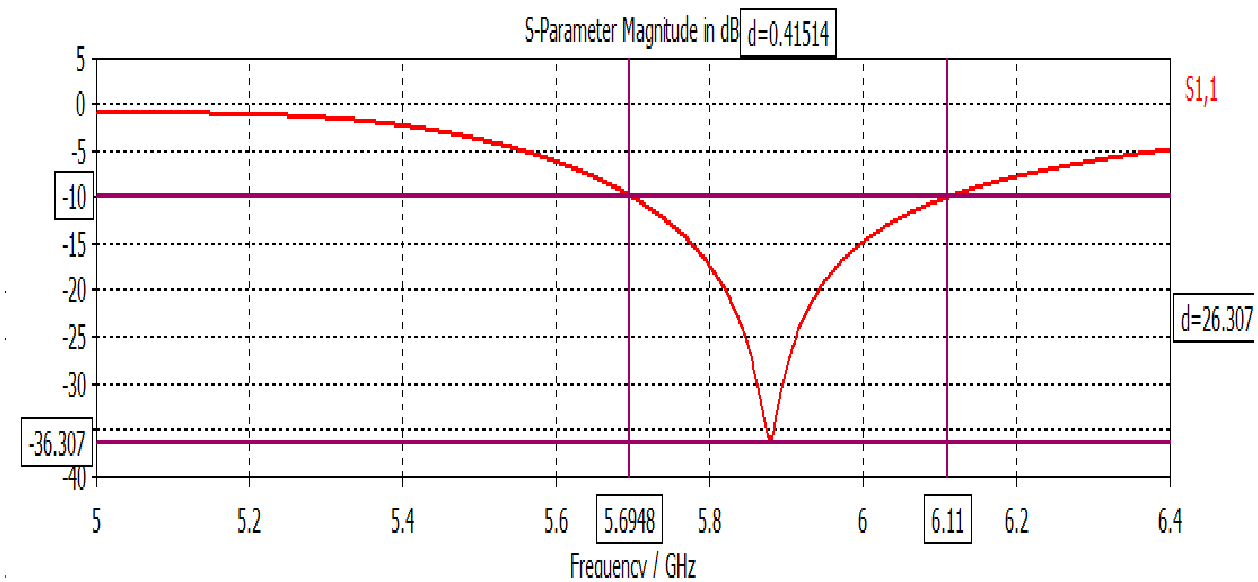


Figure 6.4: Bandwidth calculation illustration

Thus when converted to percentage it is calculated as

Bandwidth = $\frac{(\mathrm{fH}-\mathrm{fL})}{fr}$ *100

Bandwidth = 7.06%

Directivity

The Directivity plot (figure 6.5) represents amount of radiation intensity i.e is equal to 5.48 dBi. The simulated antenna radiates more in a particular direction as compared to the isotropic antenna which radiates equally in all directions, by an amount of 5.48 dBi

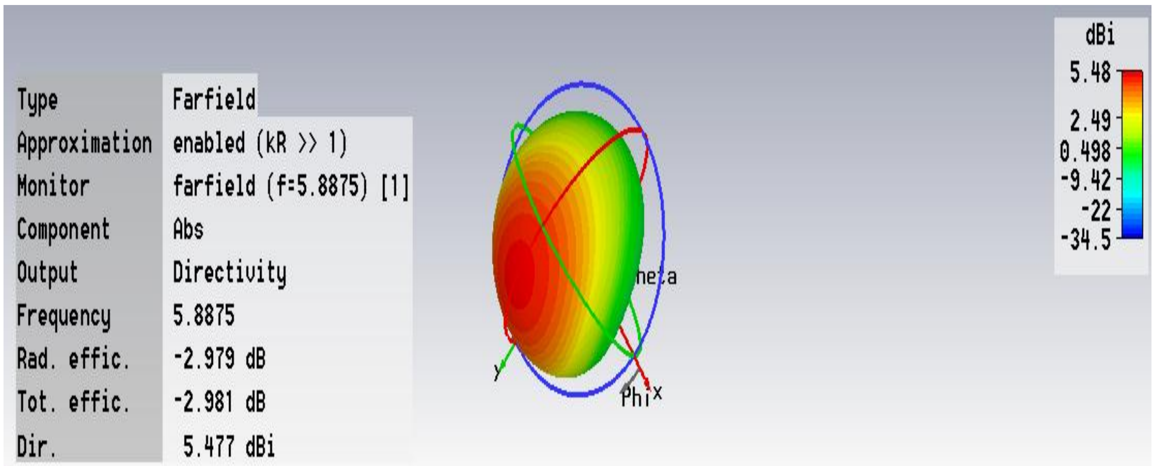


Figure 6.5: Directivity (3D view) at 5.8875GHz

From polar plot view (figure 6.6) of the directivity, it can be seen that at a frequency of 5.8875, directivity is 5.5 dBi. The main lobe direction 155.0 degree with main lobe directed at an angle of 5.0 degree, having angular beam-width of 123.7 degree.

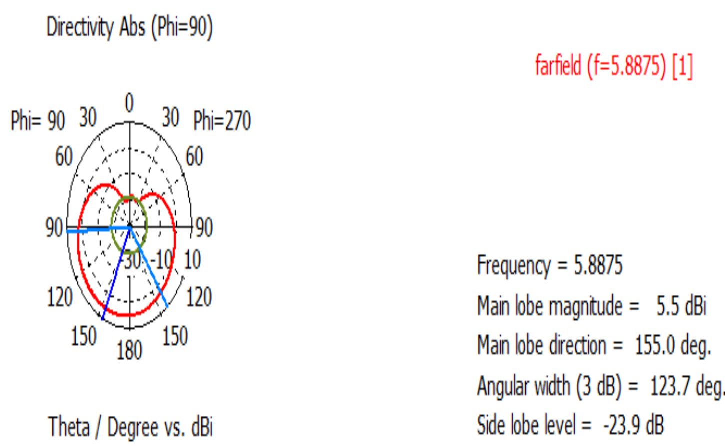


Figure 6.6: Directivity (polar plot) at 5.8875GHz

Gain

The gain plot (figure6.7) gives the gain = 2.5 dB. The gain of the antenna in a particular direction is more as compared to isotropic antenna radiating in all directions which is very useful for PPDR applications in 5.850 GHz-5.925 GHz providing a better performance.

From polar plot view of the gain, it can be seen that at a frequency of 5.8875 GHz, gain is 2.5 dB, radiation pattern obtained is directive with main lobe directed at an angle of 155.0 degree, having angular beam width of 123.7 degree. The magnitude of the main lobe is 2.5dB.

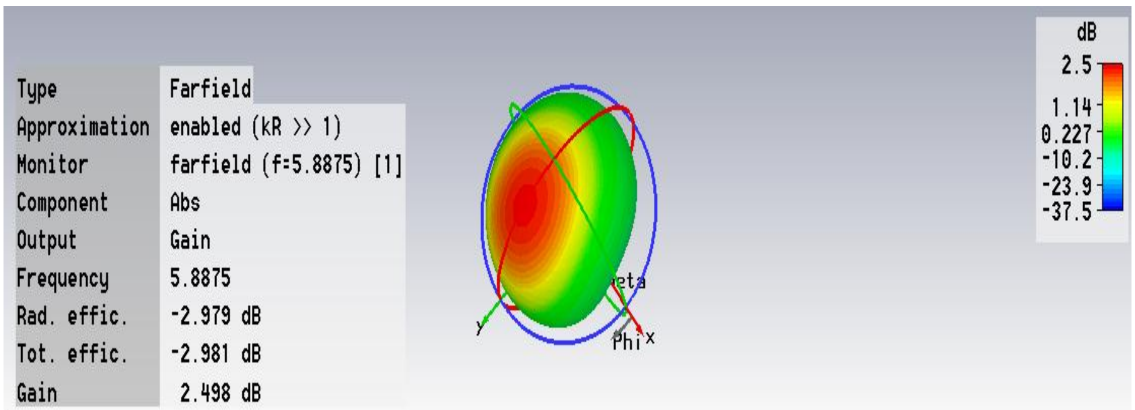


Figure 6.7: Gain of the designed Antenna (3D view) at 5.8875GHz

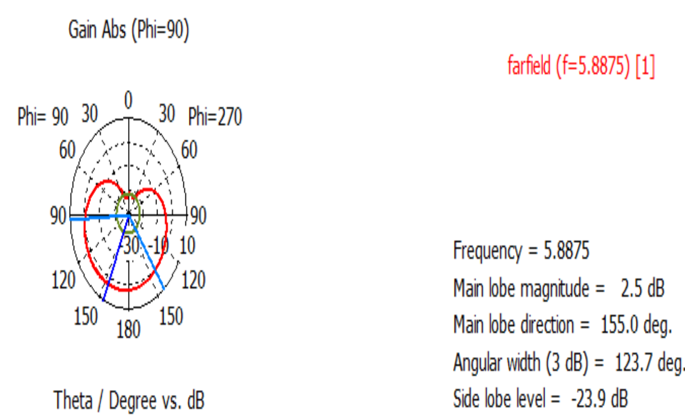


Figure 6.8: Gain of the designed Antenna (polar plot) at 5.8875 GHz

VSWR

From the antenna parameters (chapter 2), the value of VSWR is supposed to be less than 2. The obtained value of VSWR for the single band aperture-coupled microstrip antenna is 1.042, which shows a good amount of power delivering to source.

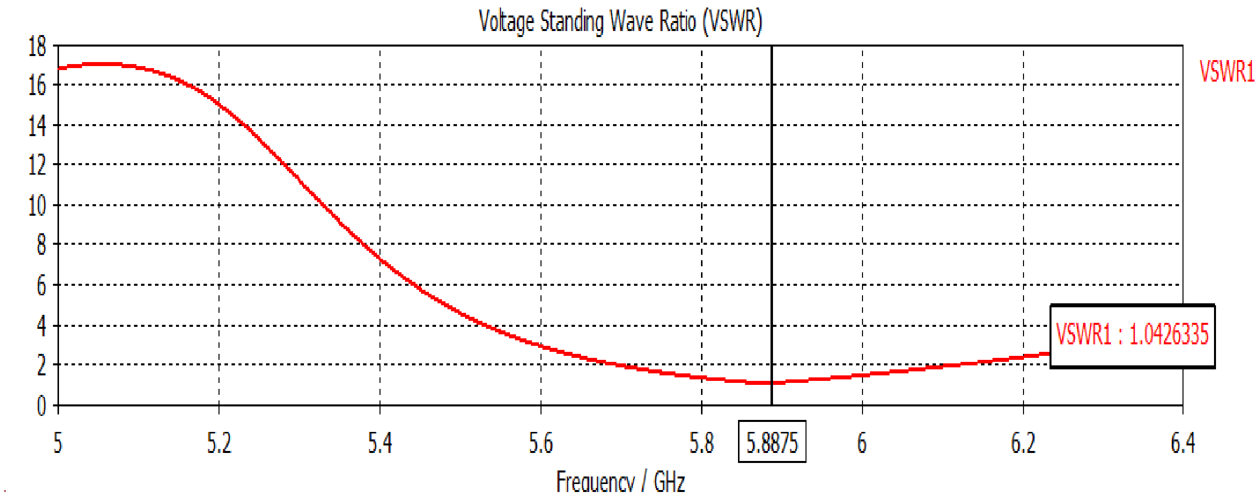


Figure 6.9: VSWR of the designed Antenna at 5.8875 GHz

Effect of Stub Length Variation:

Feed point should be chosen in such a way so that there is a good impedance match between the microstrip line impedance and the input impedance of the patch element. For maximum coupling, it should be placed perpendicular to the slot [6]. The value was chosen as $\lambda g/4$ = 6.5285 but was adjusted to 2.572 mm.

Effect of Slot Length Variation:

The smaller the size of the aperture, larger is the coupling to the patch. Coupling level is primarily decided by the slot length. Resonant value of aperture was taken as to provide maximum coupling. The bandwidth position itself to different frequeny as it changes.

6.1.2 Design of Dual Band aperture Coupled Microstrip Antenna

The antenna has to be designed in such a way that it operates in WiMAX standard. A dual band operation can be obtained by inserting a U slot of the desired dimension in ground plane and patch.

Arlon AR 600 having $\epsilon_{r=}$=6 is used for the lower substrate and Rogers RO4003 having $\epsilon_{r=}$=3.55 is used for upper substrate. The value of h is chosen as 1.6 mm.

According to the equation 4.3 the dimension of patch is calculated for $\epsilon_{r=}$=4.3 and h=1.35. Matlab code is used to calculate width and length of the patch.

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

Table 4 Design Specifications of Single Band

W	40	La	3.3
L	32	Ls1	11
Wp	28	Ls2	6
Lp	21	Mt	0.05
Bu	0.5	Ta	12
Bs	1	Ts	3.8
Ha	26	Wa	8
Hs	10	Ws	10
H	1.6	Ha	3.1

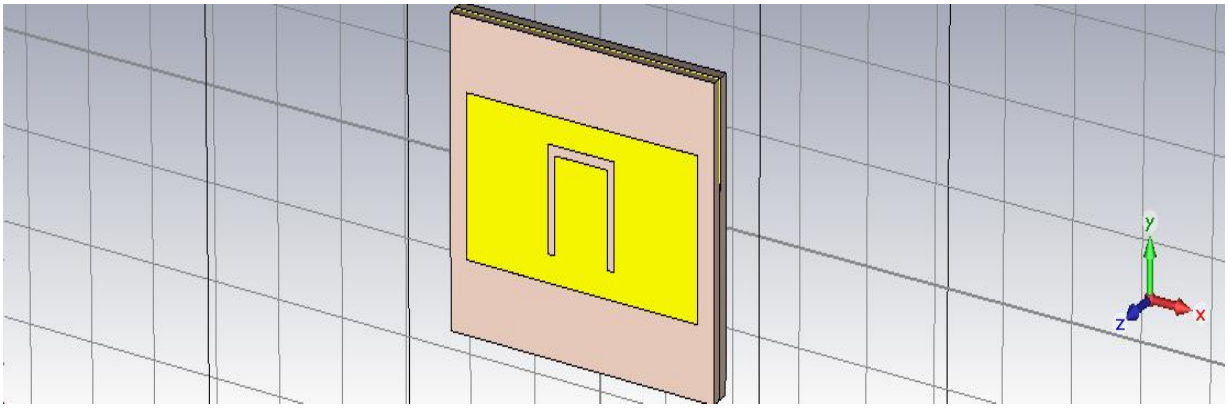


Figure 6.10: Designed structure on CST Microwave Studio

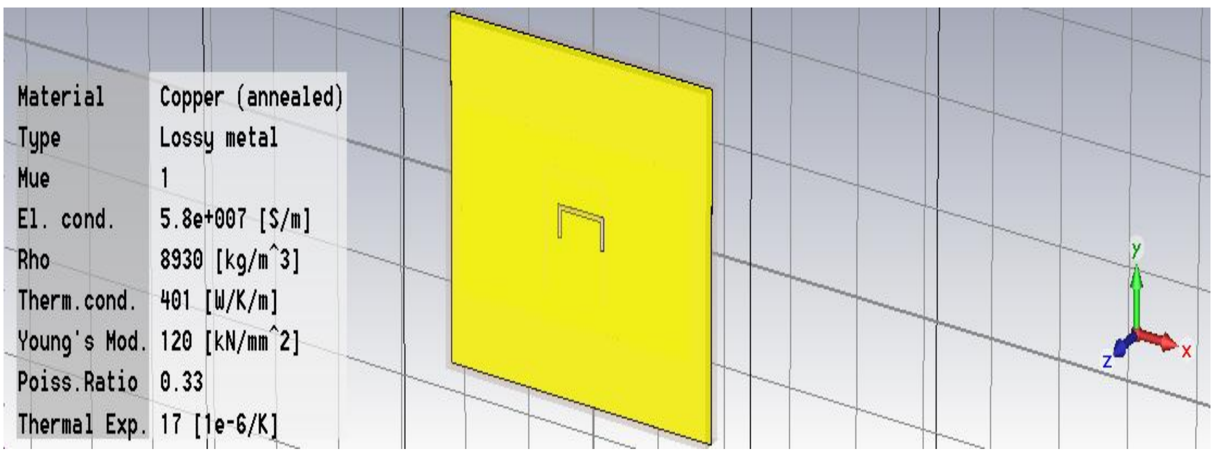


Figure 6.11: Designed structure on CST Microwave Studio of aperture U Slot

Return Loss

Figure 6.12 shows the S11 parameters (return loss) for the proposed antenna resonates at 9.55GHz having value of -40dB. The bandwidth of the antenna can be said to be those range of frequencies over which the return loss is greater than -10 dB (corresponds to a VSWR of 2). Thus, the bandwidth of antenna can be calculated from return loss versus frequency plot. The bandwidth of the proposed patch antenna is 143 GHz and resonant frequency is 9.55GHz . More is the return loss means more of the coupling. If coupling is more than the antenna will have more directivity, thereby increasing the gain of the antenna.

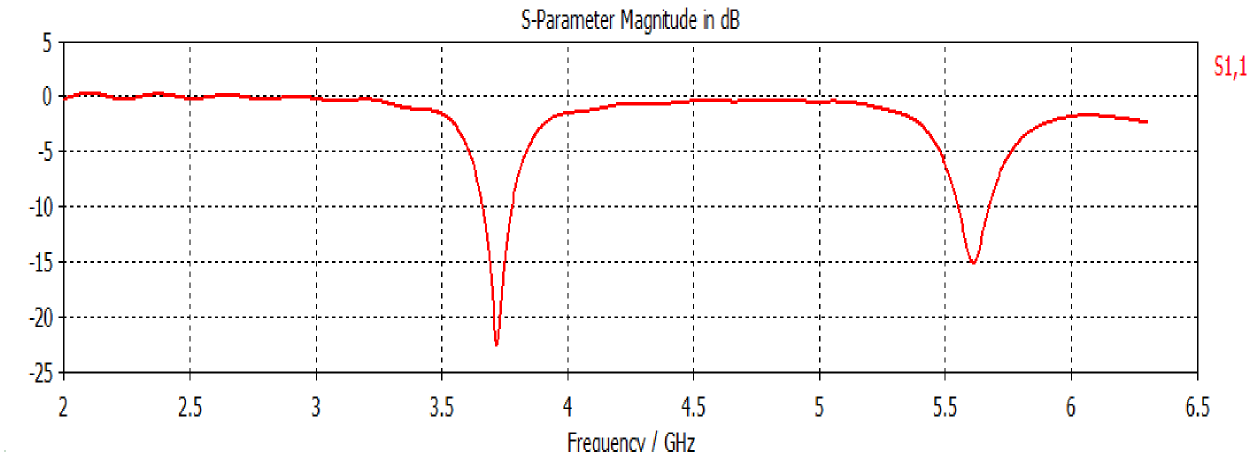
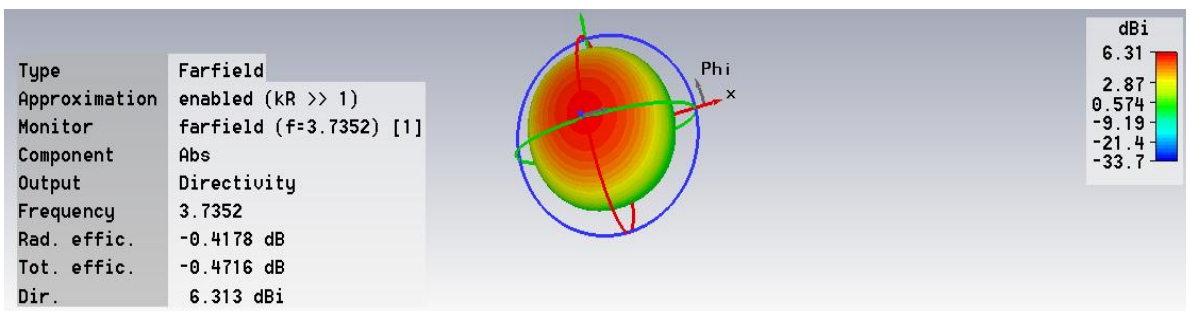


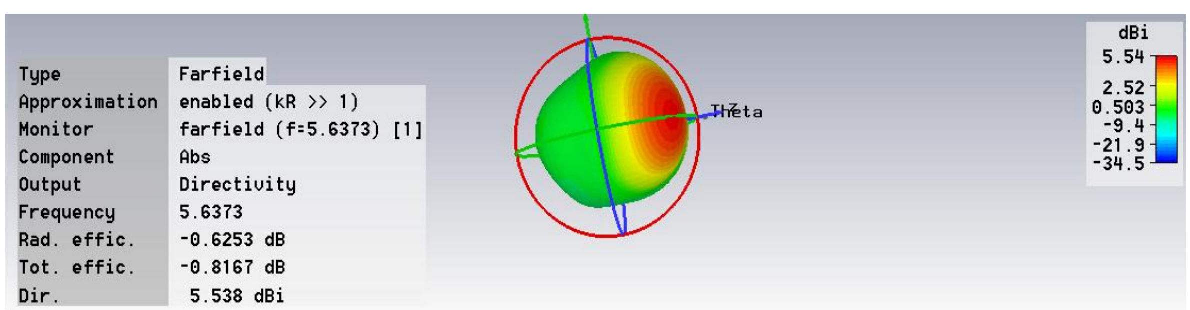
Figure 6.12: Return Loss S11 (in dB) at 3.7 GHz and 5.6 GHz

Directivity

The Directivity plot (figure 6.13 a,b) represents amount of radiation intensity i.e is equal to 6.31 dBi for 3.7352 GHz and 5.54 dBi for 5.6373 GHz . The simulated antenna radiates more in a particular direction as compared to the isotropic antenna which radiates equally in all directions, by an amount of 6.31 dBi and 5.54 dBi.



(a)

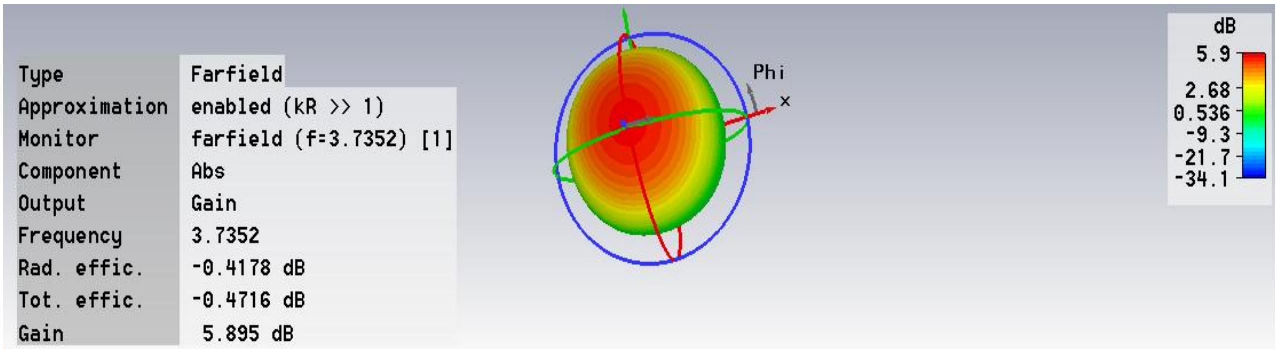


(b)

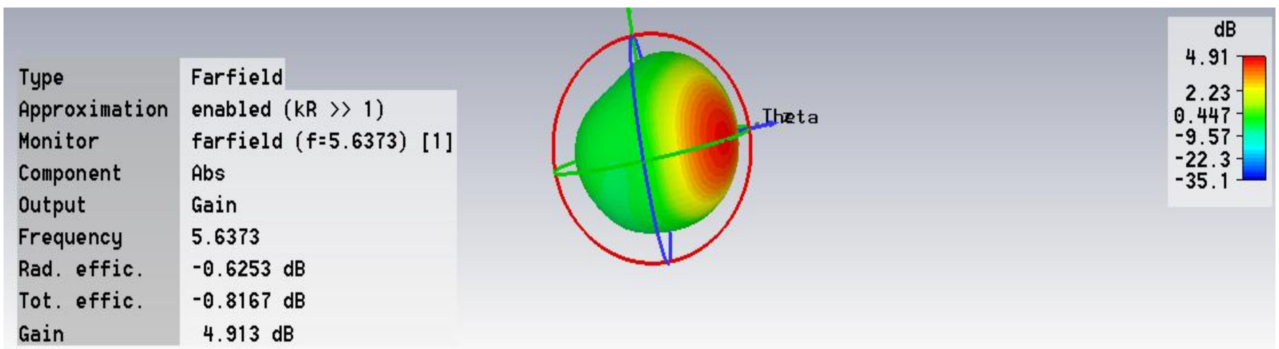
Figure 6.13: Directivity (3D view) (a) at 3.7352GHz and (b)5.6373

Gain

The Gain plot figure 6.14 (a,b) gives the gain 5.9 dB and 4.91 dB at 3.7352 GHz and 5.6373 GHz respectively.



(a)

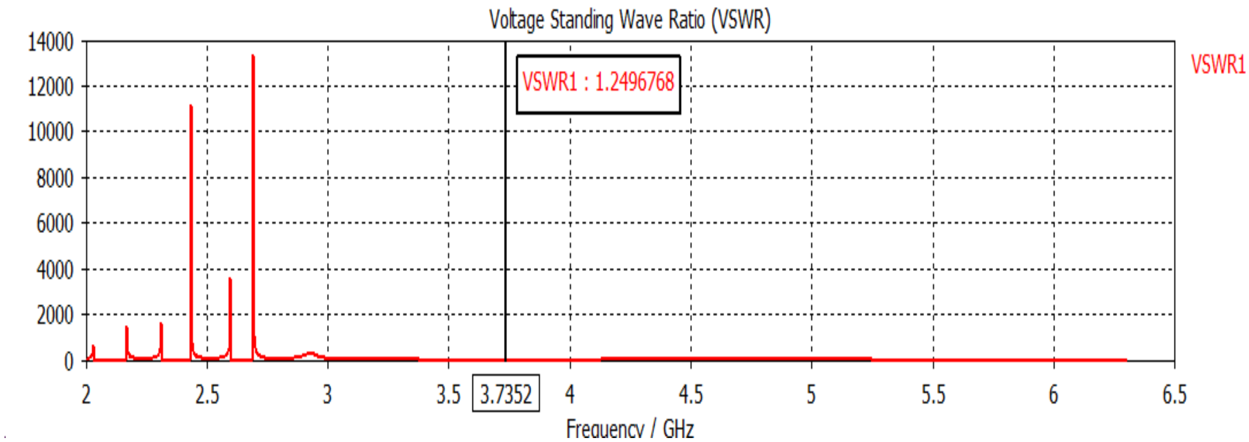


(b)

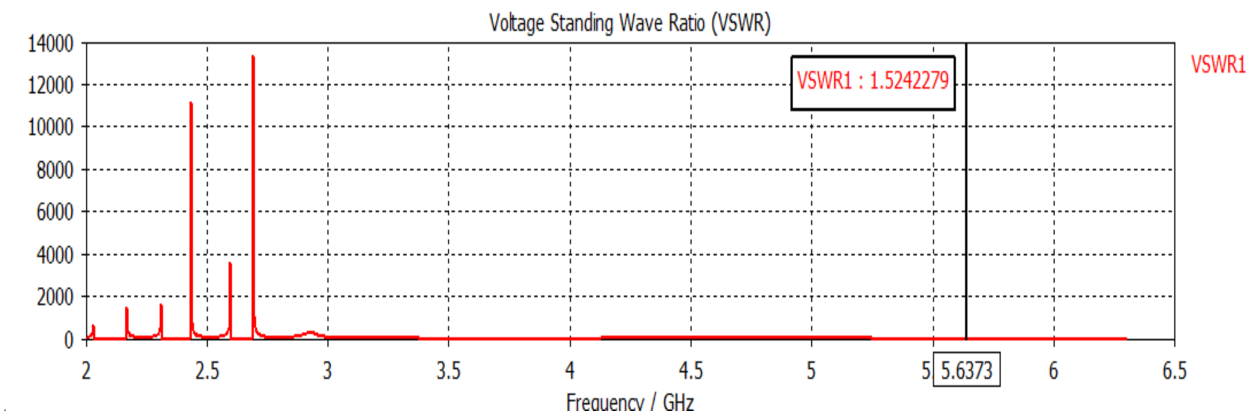
Figure 6.14: Gain of the designed Antenna (3D view) (a) at 3.7352 GHz and (b) 5.6373GHz

VSWR

Figure 5.15 (a,b) shows the values of VSWR at the resonant frequency. The value of VSWR is 1.24 and 1.52 at 3.7352 GHz and 5.6373 GHz. The values are very much appreciated at the dual band for operation of aperture-coupled antenna.



(a)



(b)

Figure 6.15: VSWR of the designed Antenna (a) at 3.7352GHz and (b) 5.6373GHz

6.1.3 Design of Triple Band aperture Coupled Microstrip Antenna

As the antenna has to be designed to operate at triple band ie 3.6 GHz, 5.2 GHz and 5.8 GHz . By inserting one more U slot in the patch the dual band operation can be converted to triple band. This antenna can be used for WiMAX standard.

According to the equation 4.3 the dimension of patch is calculated for $\epsilon_{r=}$=4.3 and h=1.35. Matlab code is used to calculate width and length of the patch.

The dimensions are kept same for the U slot as in dual band antenna.The various values of the triple band antenna are as

Table 5 Design Specifications of Triple Band Antenna

L	33	T1	4.61
W	39	L2	12.24
Lp	23.21	W2	17
Wp	29	V2	2.03
L1	7.5	H2	9.86
W1	6	T2	4.34
B1	1		
H1	6		

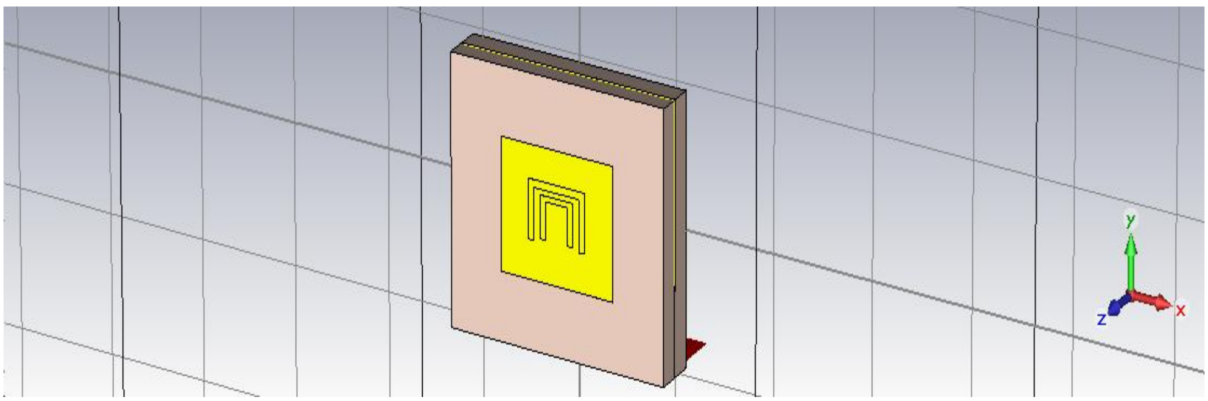


Figure 6.16: Designed structure on CST Microwave Studio

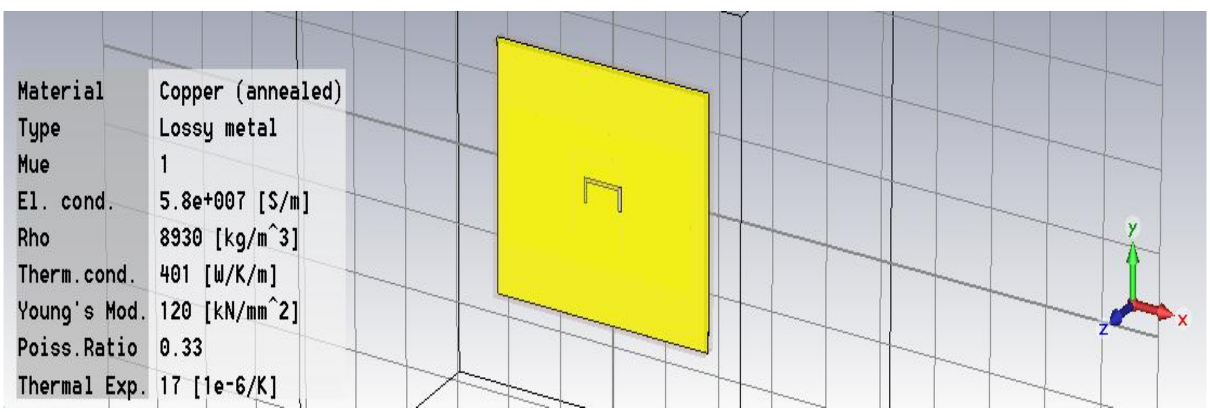


Figure 6.17: Simulation Setup and Result of Single Band Antenna at PPDR (5.850 GHz-5.925 GHz)

Return Loss

Figure shows the S11 parameters (return loss) for the proposed antenna resonates at 3.6 GHz, 5.2 GHz and 5.8 GHz having value of -17.78dB,-20.26 and -27.05. As, we know that the bandwidth of antenna can be calculated from return loss versus frequency plot. The bandwidth of the proposed patch antenna in terms of percentage bandwidth is 9.58, 6.34, and 21.86. It is clear that this configuration can operate at WiMAX besides at PPDR band according to NFAP IND 73. The high speed and bandwidth requirement is fulfilled. The 5.8 GHz band is utilized for PPDR as it has enough BW to support so.

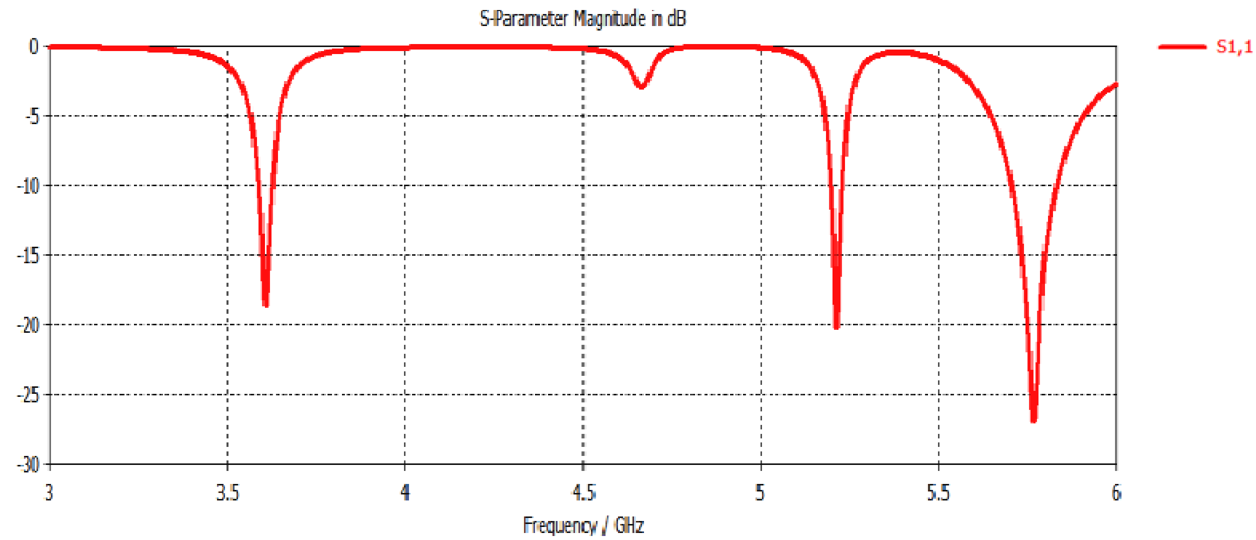
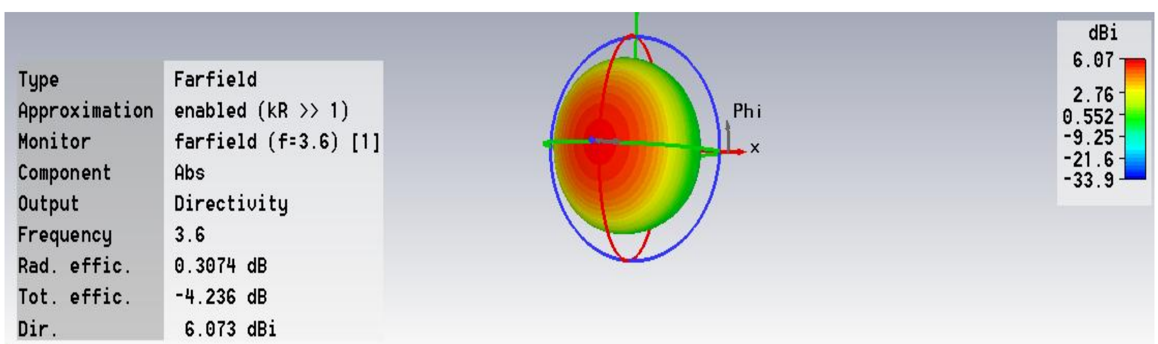


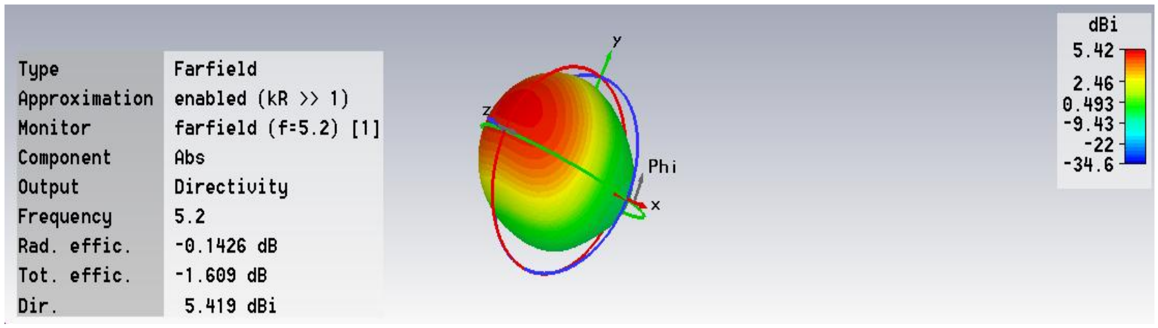
Figure 6.18: Return Loss S11 (in dB) at 3.6 GHz, 5.2 GHz and 5.8 GHz

3.2.3 Directivity

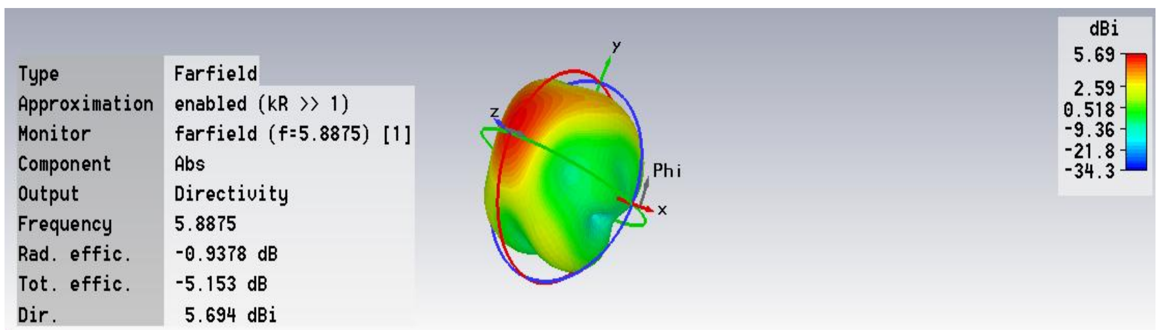
The Directivity plot (figure 3.4) represents amount of radiation intensity for the antenna i.e is equal to 6.07 dBi, 5.42 dBi, & 5.69 respectively for 3.6 GHz,5.2 GHz, & 5.8875.5.8875 GHz is the middle point in PPDR used band, so the value crosspoding to this is calculated. The triple band antenna radiates more in a z axis as compared to the isotropic antenna which radiates equally in all directions.



(a)



(b)



(c)

Figure 6.19: Directivity (3D view) at (a) 3.6GHz, (b) 5.2 GHz and (c) 5.8875GHz

Gain

The Gain plot, gives the gain = 9.152 dB. The gain of the antenna in a particular direction is more as compared to isotropic antenna radiating in all directions which is very useful for WLAN applications in X-Band providing a better performance. From polar plot view of the gain, it can be seen that at a frequency of 10GHz, gain is 9.152dB, radiation pattern obtained is omnidirectional with main lobe directed at an angle of 5.0 degree, having angular beam width of 81.4 degree. The magnitude of the main lobe is 9.2dB.

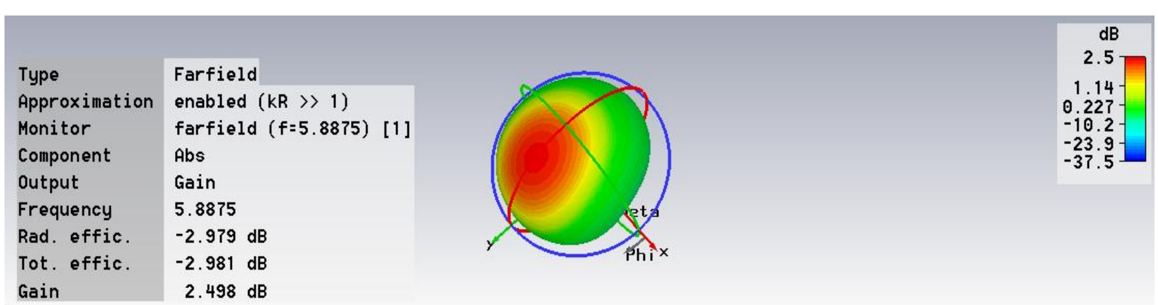


Figure 6.20: Gain of the designed Antenna (3D view) at 9.55GHz

Chapter 7

7.1 CONCLUSION AND FUTURE SCOPE

Conclusion

Three antennas have been designed using the aperture coupled feed. All three antennas exhibit greater than 6% percent bandwidths. The triple band aperture-coupled antenna satisfies the bandwidth requirement and inclusion of PPDR band into a single microstrip antenna.

The three configurations of microstrip patch antenna using aperture coupled feed uses a rectangular aperture slot for single band operation while U shaped aperture for dual and triple band operation. The first is the typical design of single band rectangular microstrip patch antenna operating at chosen PPDR band resonating at 5.879 GHz, the second is the dual band microstrip patch antenna using U and the third is the triple band microstrip patch antenna using two inverted U slot. The various antenna parameters like return loss, VSWR, directivity, gain, bandwidth and operating frequency are studied for antenna designing. The effect of physical parameters on the aperture coupled MSA are also studied in this this dissertation .

Future Scope

Project Recommendations

The following list contains possible future student projects that would extend the research and testing performed in this dissertation .

• Design and build aperture coupled patch antennas operating at various frequencies with different substrate materials satisfying the discussed literature.

• The parametric study can be carried out with the help of EM theory.

• Compare the performance of similar microstrip fed, probe fed, and aperture coupled patch antennas.

Electromagnetic Band Gap Structure (EBG)

It reduces the effect of surface waves as a function of frequency. It is also able to provide relatively broadband frequency performance. In EBG only one out of ε_r and μ_r is negative.

Metamaterials

A metamaterial has the tendency to bend visible light rays in the opposite sense from traditional refractive media. It uses is a metallic or semiconductor substance whose physical properties depend on its inter-atomic structure.

Other Feeding Techniques

Besides using various feed mechanisms a circularly polarized antenna can also be used in future to design the same microstrip patch antennas.

Appendix

APPENDIX A

Matlab code for determining the length and width of antenna related to figure (2.2)

```
clc
clear all
close all
epsilon=input('Enter the numerical value of Epsilon');
rfreq1=input('Enter radiation frequency');
rfreq=rfreq1*10^9
h=input('Enter the thickness of the substrate');
h=h/10;
c=3*10^10;
w=(1/(2*rfreq*c^(-1)))*(2/(epsilon+1))^0.5
aa=(epsilon+1)/2
bb=(epsilon-1)/2
cc=12*(h/w)
epsiloneff=aa + bb*(1+cc)^-0.5
deltal=h*0.412*(epsiloneff+0.3)*((w/h)+0.264)*(epsiloneff-0.258)^(-1)*((w/h)+0.8)^(-1)
l=(2*rfreq*(epsiloneff)^0.5*c^(-1))^(-1)-2*deltal
leff=l-2*deltal
```

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