DECLARATION

This declaration is to clarify that all of the submitted contents of this project are original in its figure, excluding those, which have been admitted specifically in the references. All the work process involved is from our own idea and creativity. All contents of this project have been submitted as a part of partial fulfillment of Bachelor of Electronics & Communications Engineering. I hereby declare that this project is the work of our own excluded for the references document and summaries that have been acknowledge.

Counter signed

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APPROVAL

This project report titled **Design and Performance Analysis of Microstrip Patch Antenna for Ultra Wide Band Application** was prepared and submitted by **Nurul Islam (Id:2012-3-55-016)** and **Jahid Hassan(Id:2013-1-55-029)** and **Abdur Rhaman Pappu (Id:2013-1-55-007)** has been found satisfactory in term of scope, quality and presentation as partial fulfillment of the requirement for the Bachelor of Electronics & Communications Engineering, East West University

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Alhamdulillah. Thanks to Allah SWT, whom with His willing giving me the opportunity to complete this Final Year Project which is title Performance **Design and Analysis of Microstrip Patch Antenna For Ultra Wide Band Application**. This final year project report was prepared for Electronics & Communication Engineering, East West University, basically for student in final year to complete the undergraduate program that leads to the degree of Bachelor of Engineering in Communication. This report is based on the methods given by the university Firstly; I would like to express my deepest thanks to**, Dr .M. Mofazzal Hossain, Professor Department of ECE** as my supervisor who had guided be a lot of task during two semesters session. I also want to thanks the lecturers and staffs of Department of ECE for their cooperation during I complete the final year project that had given valuable information, suggestions and guidance in the compilation and preparation this final year project report.

ABSTRACT

The study of microstrip patch antennas has made great progress in recent years. Compared with conventional antennas, microstrip patch antennas have more advantages and better prospects. They are lighter in weight, low volume, low cost, low profile, smaller in dimension and ease of fabrication and conformity. Moreover, the microstrip patch antennas can provide dual polarization (circular and linear polarizations), dual-band operation, frequency agility, broad band-width, feedline flexibility, beam scanning omni directional patterning. In this thesis we investigated the performance of an inset-feed microstrip patch antenna. It is found that the percentage bandwidth of the designed antenna is 3.4% with a realized gain of 3.95dB and VSWR of 1.096. These results are comparable even better compared with those found in literature.

Key Words: Microstrip patch antenna (MPA), Inset-Feed, UWB, CST Microwave Studio

Contents

Chapter 1
Introduction

1.1 INTRODUCTION

Ultra-wideband (also known as UWB, ultra-wide band and ultra band) is a radio technology pioneered by Robert A. Schorton, and others that can use a very low energy level for short-range, high-bandwidth communications over a large portion of the radio spectrum.[1] UWB has traditional applications in non-cooperative radar imaging. Most recent applications target sensor data collection, precision locating and tracking applications.[2]

Ultra-wideband is a technology for transmitting information spread over a large bandwidth (>500 MHz); this should, in theory and under the right circumstances, be able to share spectrum with other users. Regulatory settings by the Federal Communications Commission (FCC) in the United States intend to provide an efficient use of radio bandwidth while enabling high-data-rate personal area network (PAN) wireless connectivity; longer-range, low-data-rate applications; and radar and imaging systems.

1.2 HISTORY AND BACKGROUND

Ultra-wideband communications is fundamentally different from all other communication techniques because it employs extremely narrow RF pulses to communicate between transmitters and receivers. Utilizing short-duration pulses as the building blocks for communications directly generates a very wide bandwidth and offers several advantages, such as large throughput, covertness, robustness to jamming, and coexistence with current radio services. The United Kingdom's spectrum auction for next-generation wireless applications generated $35.4 billion in April 2000 [1]. Ultra-wideband communications is not a new technology; in fact, it was first employed by Guglielmo Marconi in 1901 to transmit Morse code sequences across the Atlantic Ocean using spark gap radio transmitters.

Approximately fifty years after Marconi, modern pulse-based transmission gained momentum in military applications in the form of impulse radars. Some of the pioneers of modern UWB communications in the United States from the late 1960s are Henning Harmuth of Catholic University of America and Gerald Ross and K. W. Robins of
Sperry Rand Corporation From the1960s to the 1990s, this technology was restricted to military and Department of Defense (DoD) applications under classified programs such as highly secure communications. However, the recent advancement in micro processing and fast switching in semiconductor technology has made UWB ready for commercial applications. Therefore, it is more appropriate to consider UWB as a new name for a long-existing technology. As

interest in the commercialization of UWB has increased over the past several years, developers of UWB systems began pressuring the FCC to approve UWB for commercial use Some of the pioneers of modern UWB communications in the United States from the late 1960s are Henning Harmuth of Catholic University of America and Gerald Ross and K. W. Robins of Sperry Rand Corporation [2].

1.3 ULTRA-WIDE BAND CONCEPTS

Traditional narrowband communications systems modulate continuous waveform (CW) RF signals with a specific carrier frequency to transmit and receive information. A continuous waveform has well-defined signal energy in a narrow frequency band that makes it very vulnerable to detection and interception.

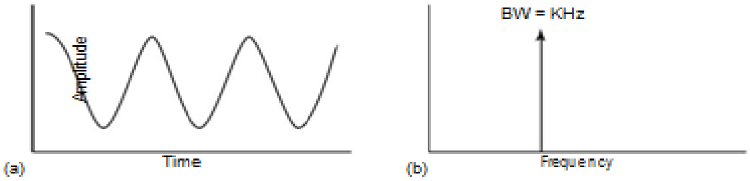


Fig 1.1: A narrowband signal in (a) the time domain and (b) the frequency domain

As mentioned in earlier, UWB systems use carrier less, short-duration (pico-second to nano second) pulses with a very low duty cycle (less than 0.5 percent) for transmission and reception of the information. A simple definition for duty cycle is the ratio of the time that a pulse is present to the total transmission time.

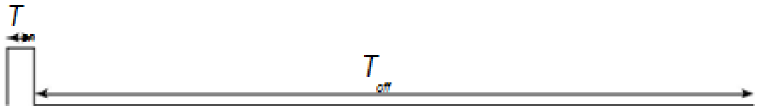


Fig 1.2: a low-duty-cycle pulse.

Ton represents the time that the pulse exists and Toff represents the time that the pulse is absent. Low duty cycle offers a very low average transmission power in UWB communications systems. The average transmission power of a UWB system is on the order of microwatts, which is a thousand times less than the transmission power of a cell phone. However, the peak or instantaneous power of individual UWB pulses can be relatively large, but because they are transmitted for only a very short time (< 1 nanosecond), the average power becomes considerably lower. The peak power of UWB pulses in some cases is reported to be about 1 watt for 1 Mbps at 1 MHz [3].Consequently, UWB devices require low transmit power due to this control over the duty cycle, which directly translates to longer battery life for handheld equipment. Since frequency is inversely related to time, the short-duration UWB pulses spread their energy across a wide range of frequencies from near DC to several giga hertz (GHz) with very low power spectral density (PSD).

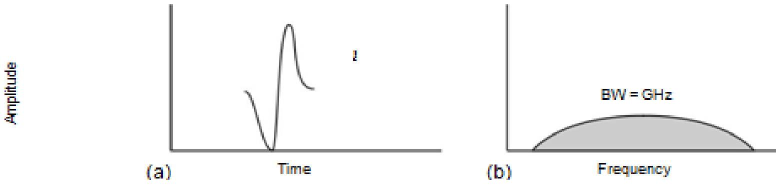


Fig 1.3: A UWB pulse in (a) the time domain and (b) the frequency domain

1.4 UWB SIGNALS

As defined by the FCC’s First Report and Order, UWB signals must have bandwidths of greater than 500 MHz or a fractional bandwidth larger than 20 percent at all times of transmission. Fractional bandwidth is a factor used to classify signals as narrowband, wideband, or ultra-wide-band and is defined by the ratio of bandwidth at –10 dB points [4] to center frequency.

$$B_f = \frac{BW}{f_c} \times 100\,\% = \frac{(f_h - f_l)}{(f_h + f_l)/2} \times 100\% = \frac{2(f_h - f_l)}{f_h + f_l} \times 100\% \qquad (1)$$

Where f_h and f_l are the highest and lowest cutoff frequencies (at the –10 dB point) of a UWB pulse spectrum, respectively.

As shown in Fig 1.4, a 500-picosecond pulse generates a large band-width in the frequency domain with a center frequency of 2 GHz. In Fig-

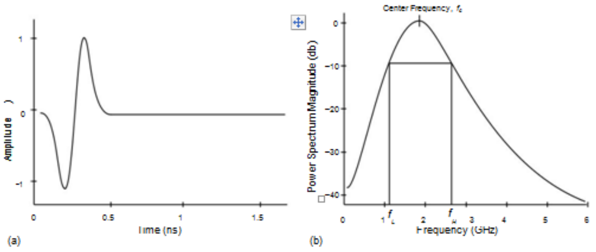


Fig 1.4: A 500-picosecond Gaussian monocycle in (a) the time domain and (b) the frequency domain

Fig 1.4, the lowest and highest cutoff frequencies at –10 dB are approximately 1.2 GHz and 2.8 GHz, respectively, which lead to a fractional bandwidth of 80 percent; this is much larger than the minimum B_f required by the FCC:

$$B_f = 2 \times \frac{(2.8 - 1.2)}{2.8 + 1.2} \times 100\% = 80\%. \tag{2}$$

1.5 ADVANTAGES

The nature of the short-duration pulses used in UWB technology offers several advantages over narrowband communications systems. In this section, we discuss some of the key benefits that UWB brings to wireless communications.

1.5.1 ABILITY TO SHARE THE FREQUENCY SPECTRUM

The FCC's power requirement of –41.3 dBm/MHz, [5] equal to 75 nano-watts/MHz for UWB systems, puts them in the category of unintentional radiators, such as TVs and computer monitors. Such power restriction allows UWB systems to reside below the noise floor of a typical narrow-band receiver and enables UWB signals to coexist with current radio services with minimal or no interference.

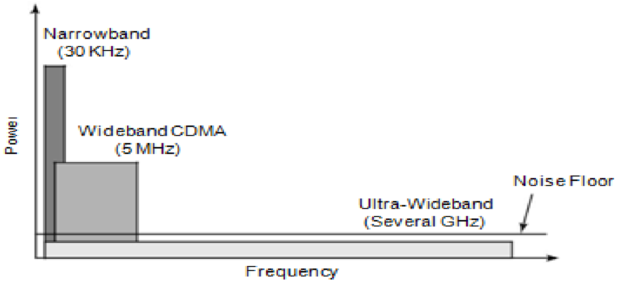


Fig 1.5 Coexistence of UWB signals with narrowband and wideband signals in the RF spectrum

1.5.2 LARGE CHANNEL CAPACITY

One of the major advantages of the large bandwidth for UWB pulses is improved channel capacity. *Channel capacity*, or data rate, is defined as the maximum amount of data that can be transmitted per second over a communications channel.

1.5.3 ABILITY TO WORK WITH LOW SIGNAL-TO-NOISE RATIOS

The Hartley-Shannon formula for maximum capacity (Equation 1–5) also indicates that the channel capacity is only logarithmically dependent on signal-to-noise ratio (SNR). Therefore, UWB communications systems are capable of working in harsh communication channels with low SNRs and still offer a large channel capacity as a result of their large bandwidth.

1.5.4 LOW PROBABILITY OF INTERCEPT AND DETECTION

Because of their low average transmission power, as discussed in previous sections, UWB communications systems have an inherent immunity to detection and intercept. With such low transmission power, the eaves-dropper has to be very close to the transmitter (about 1 meter) to be able to detect the transmitted information. In addition, UWB pulses are time modulated with codes unique to each transmitter/receiver pair. The time modulation of extremely narrow pulses adds more security to UWB transmission, because detecting picoseconds pulses without knowing when they will arrive is next to impossible. Therefore UWB systems hold significant promise of achieving highly secure, low probability of intercept and detection (LPI/D) communications that is a critical need for military operations. The abbreviation *dBm* stands for decibels per milli watt. Hence, –41.3 dBm/MHz is equal to 75 nW/MHz [5].

1.5.5 RESISTANCES TO JAMMING

Unlike the well-defined narrowband frequency spectrum, the UWB spectrum covers a vast range of frequencies from near DC to several gigahertz's and offers high processing gain for UWB signals. Processing gain (PG) is a measure of a radio system's resistance to jamming and is defined as the ratio of the RF bandwidth to the information bandwidth of a signal:

$$PG = \frac{RF\ Bandwidth}{Information\ \ Bandwidth} \tag{3}$$

The frequency diversity caused by high processing gain makes UWB signals relatively resistant to intentional and unintentional jamming, because no jammer can jam every frequency in the UWB spectrum at once. Therefore, if some of the frequencies are jammed, there is still a large range of frequencies that remains untouched. However, this resistance to jamming is only in comparison to narrowband and wideband systems.

1.5.6 HIGH PERFORMANCES IN MULTIPATH CHANNELS

The phenomenon known as multipath is unavoidable in wireless communications channels. It is caused by multiple reflections of the transmit-ted signal from various surfaces such as buildings, trees, and people. The straight line between a transmitter and a receiver is the line of sight (LOS); the reflected signals from surfaces are non-line of sight (NLOS).

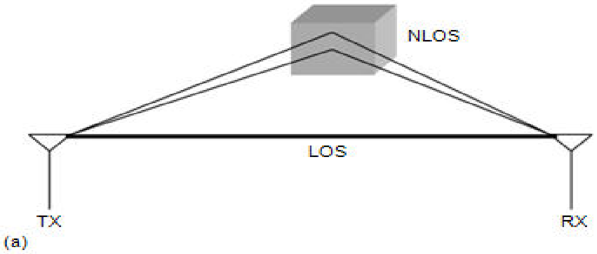


Fig 1.6**:** The multipath phenomenon in wireless links.

As shown in Fig 1.6, the effect of multipath is rather severe for narrowband signals; it can cause signal degradation up to –40 dB due to the out-of-phase addition of LOS and NLOS continuous waveforms.

1.5.7 SUPERIOR PENETRATION PROPERTIES

Unlike narrowband technology, UWB systems can penetrate effectively through different materials. The low frequencies included in the broad range of the UWB frequency spectrum have long wavelengths, which allows UWB signals to penetrate a variety of materials, including walls. This property makes UWB technology viable for through-the-wall communications and ground-penetrating radars. However, the material penetration capability of UWB signals is useful only when they are allowed to occupy the low-frequency portion of the radio spectrum.

1.5.8 SIMPLE TRANSCEIVER ARCHITECTURE

UWB transmission is carrier less, meaning that data is not modulated on a continuous waveform with a specific carrier frequency, as in narrowband and wideband technologies. Carrier less transmission requires fewer RF components than carrier-based transmission. For this reason UWB transceiver architecture is significantly simpler and thus cheaper to build.

As shown in Figure 1.7, the UWB transceiver architecture is considerably less complicated than that of the narrowband transceiver. The transmission of low-powered pulses eliminates the need for a power amplifier

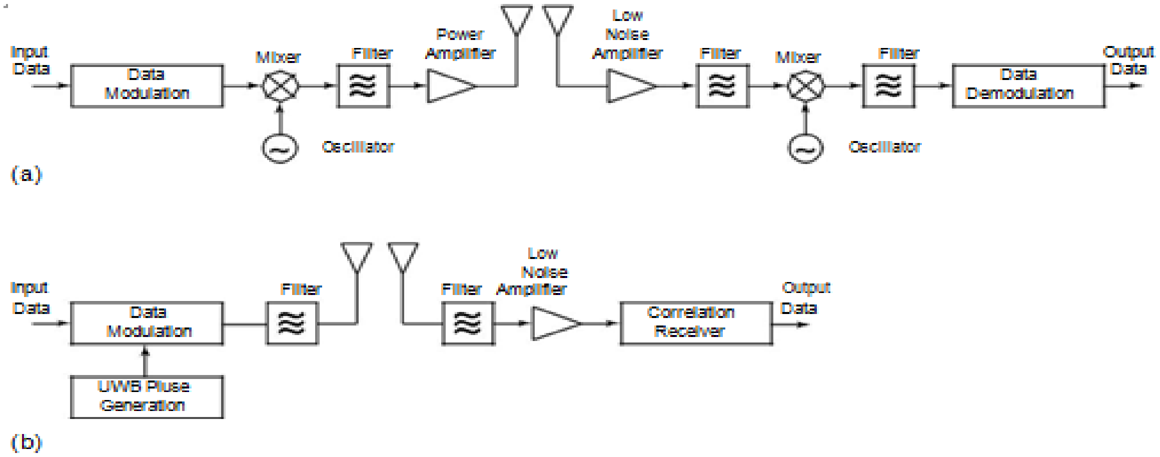


Fig 1.7(a) A typical narrowband transceiver architecture (b) An example of a UWB transceiver architecture.

1.6 CHALLENGES

UWB technology for communications is not all about advantages. In fact, there are many challenges involved in using nanosecond-duration pulses for communications. Some of the main difficulties of UWB communications are discussed in the following subsections.

1.6.1 PULSE-SHAPE DISTORTION

The transmission characteristics of UWB pulses are more complicated than those of continuous narrowband sinusoids. A narrowband signal remains sinusoidal throughout the transmission channel. However, the weak and low-powered UWB pulses can be distorted significantly by the transmission link. In a vacuum, all electromagnetic waveforms travel at the speed of light, $c = 3 \times 10^8$ meters per second [6].

1.6.2 CHANNEL ESTIMATION

Channel estimation is a core issue for receiver design in wireless communications systems. Because it is not possible to measure every wireless channel in the field, it is important to use training sequences to estimate channel parameters, such as attenuations and delays of the propagation path. Given that most UWB receivers correlate the received signal with a predefined template signal, prior knowledge of the wireless channel parameters is necessary to predict the shape of the template signal that matches the received signal.

1.6.3 HIGH-FREQUENCY SYNCHRONIZATION

Time synchronization is a major challenge and a rich area of study in UWB communications systems. As with any other wireless communications system, time synchronization between the receiver and the transmitter is a must for UWB transmitter/receiver pairs. However, sampling and synchronizing nanosecond pulses place a major limitation on the design of UWB systems. In order to sample these narrow pulses, very fast (on the order of gigahertz) analog-to-digital converters (ADCs) are needed.

1.6.4 MULTIPLE-ACCESS INTERFERENCE

In a multiuser or a multiple-access communications system, different users or devices send information independently and concurrently over a shared transmission medium (such as the air interface in wireless communications). At the receiving end, one or more receivers should be able to separate users and detect information from the user of interest. Interference from other users with the user of interest is called multiple-access interference (MAI), which is a limiting factor to channel capacity and the performance of such receivers.

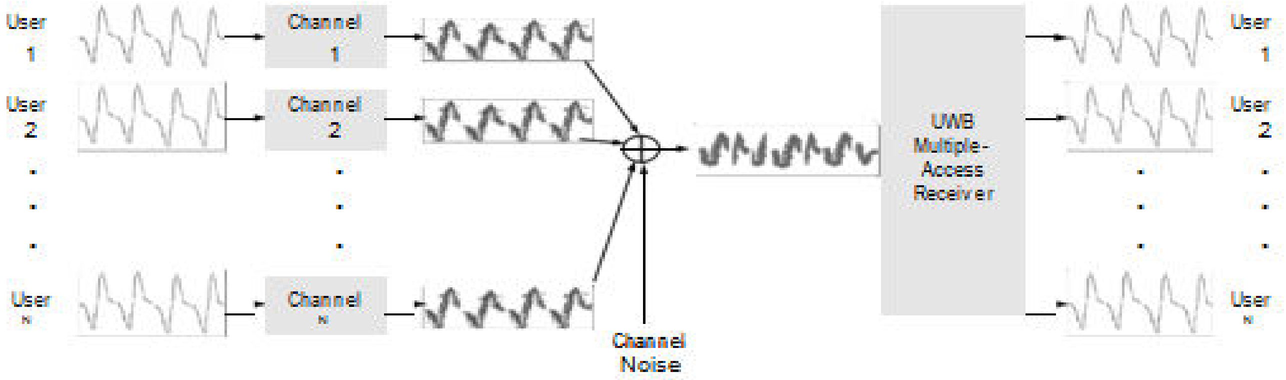


Fig 1.8: A UWB multiple-access channel

As shown in Figure 1.9, separating each user's information from the combination of heavily distorted and low-powered UWB signals from all users is a very challenging task. As defined by the FCC's First Report and Order, UWB signals must have bandwidths of greater than 500 MHz or a fractional bandwidth larger than 20 percent at all times of transmission [7].

Chapter 2

Patch Antenna

2.1 INTRODUCTION

Antenna is a transducer designed to transmit or receive electromagnetic waves. Microstrip antennas have several advantages over conventional microwave antenna and therefore are widely used in many practical applications. Microstrip antennas in its simplest configuration are shown in Fig1. It consists of a radiating patch on one side of dielectric substrate (Єr≤10), which has a ground plane on other side.

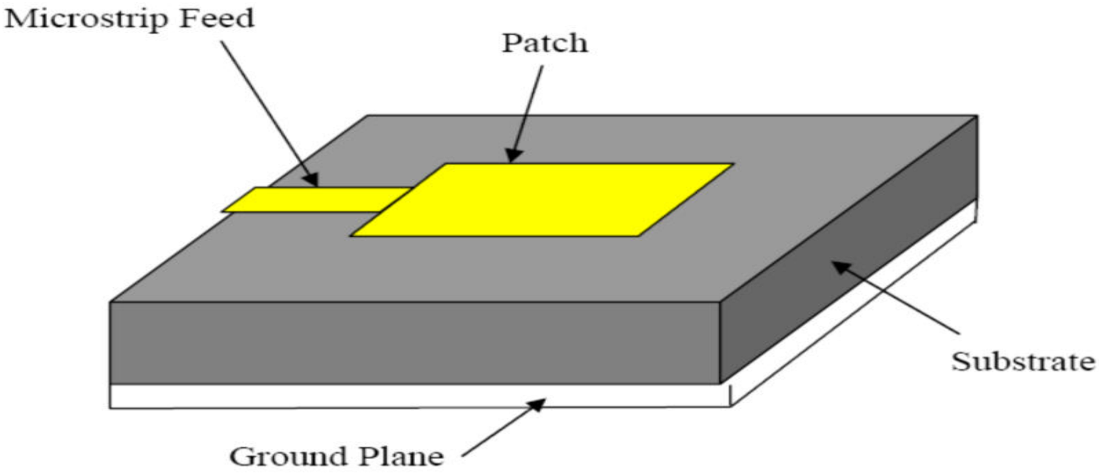


Fig 2.1: Microstrip antenna configuration

2.2 ANTENNA

Antenna is a transition device or transducer between a free-space wave and a guided wave and vice-versa. Transmission lines or waveguides are designed to minimize radiation whereas, antenna is designed to radiate or receive energy as efficiently as possible. Antenna (like the eye) converts electromagnetic photons into electric currents. Unlike the eye, antenna can also convert electric energy from a circuit into photons radiated into space.

An antenna is used to radiate electromagnetic energy efficiently and in desired directions. Antennas act as matching systems between sources of electromagnetic energy and space. The goal in using antennas is to optimize this matching

2.3 CLASSIFICATION OF ANTENNA

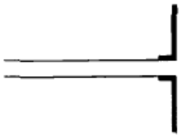
On the basis of radiation there are three types of antenna. These are –

1. **Isotropic:** A hypothetical lossless antenna having equal radiations in all directions. These antennas don't exist in practice, but are sometimes discussed as a means of comparison with real antennas**.**
2. **Omni directional:** Some antennas may also be described as "omnidirectional", which for an actual means that it is isotropic in a single plane.
3. **Directional:** A directional antenna is one having property of receiving or radiating electromagnetic energy more effectively in some particular direction than in others**.**

On the basis of physical structure there are five types of antenna

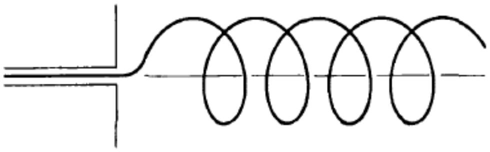
1. Wire Antenna

- Dipole antenna
- Monopole
- Helix antenna
- Loop antenna (may be rectangular, circular, elliptical etc).



(a) Dipole

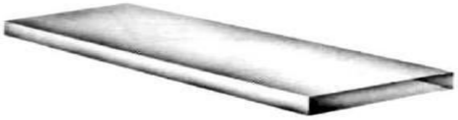
(b) Circular (square) loop



(c) Helix

(a) Pyramidal horn

(b) Conical horn



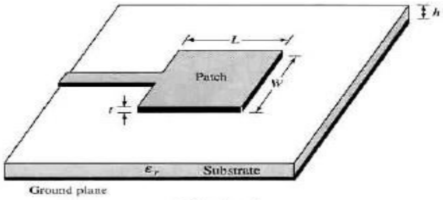
(c) Rectangular waveguide

2. Aperture Antenna

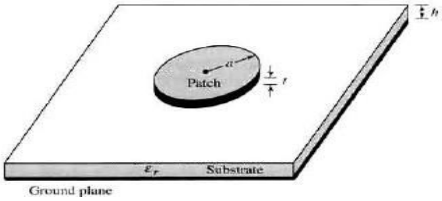
- Horn antenna
- Rectangular waveguide

3. Planar Antenna

- Microstrip patch antenna,
- Planner Inverted F- Antenna



(a) Rectangular

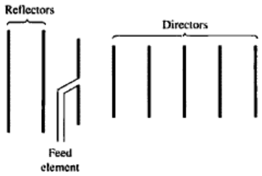


- Dual Inverted F-Antenna
- Planner L-Antenna

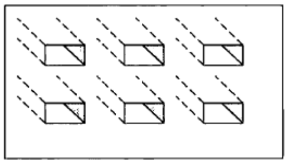
4. Reflector antenna

- High Gain Antenna
- Dimensions much larger
- Used for long distance (millions of miles) communication

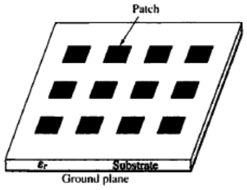
4. **Array antenna**
   - To achieve
   - Desired radiation pattern
   - High Directivity
   - High Gain



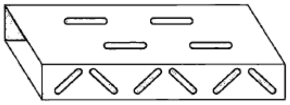
(a) Yagi-Uda array



(b) Aperture array



(c) Microstrip patch array



(d) Slotted-waveguide array

2.4 PATCH ANTENNA

Microstrip patch Antennas (also just called *patch antennas*) are among the most common antenna types in use today, particularly in the popular frequency range of 1 to 6 GHz. This type of antenna had its first intense development in the 1970s, as communication systems became common at frequencies where its size and performance were very useful. A microstrip patch antenna (MPA) consists of a conducting patch of any planar or nonplanar geometry on one side of a dielectric substrate with a ground plane on other side. It is a popular printed resonant antenna for narrow-band microwave wireless links that require semi hemispherical coverage. Due to its planar configuration and ease of integration with microstrip technology, the microstrip patch antenna has been heavily studied and is often used as elements for an array. A large number of microstrip patch antennas have been studied to date. An exhaustive list of the geometries along with their salient features is available [1]. The rectangular and circular patches are the basic and most commonly used microstrip antennas. These patches are used for the simplest and the most demanding applications. Rectangular geometries are separable in nature and their analysis is also simple. The circular patch antenna has the advantage of their radiation

Microstrip or patch antennas are becoming increasingly useful because they can be printed directly onto a circuit board thickness h with permittivity ε_r. The thickness of the ground plane or of the microstrip is not critically important. Typically the height *h* is much smaller than

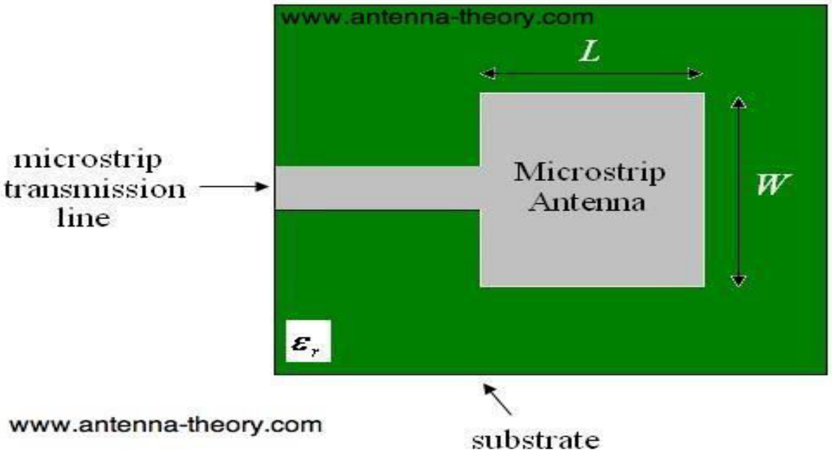


Fig 2.2 :(a) Top view of the patch antenna

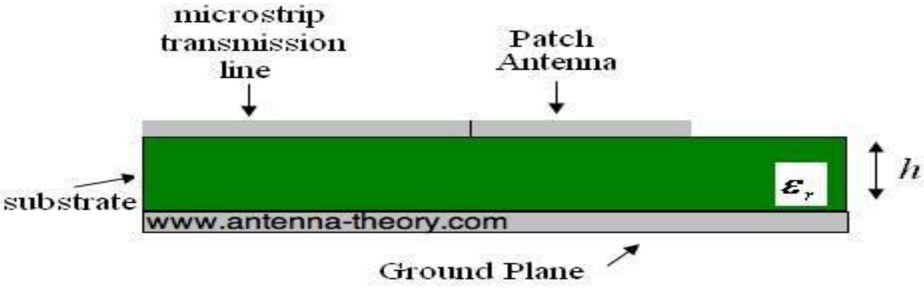


Fig 2.2 :(b) Side view of the patch antenna

2.5 GEOMETRY OF PATCH ANTENNA

Micro strip patch antenna consists of radiation patch, dielectric substrate and ground plan as

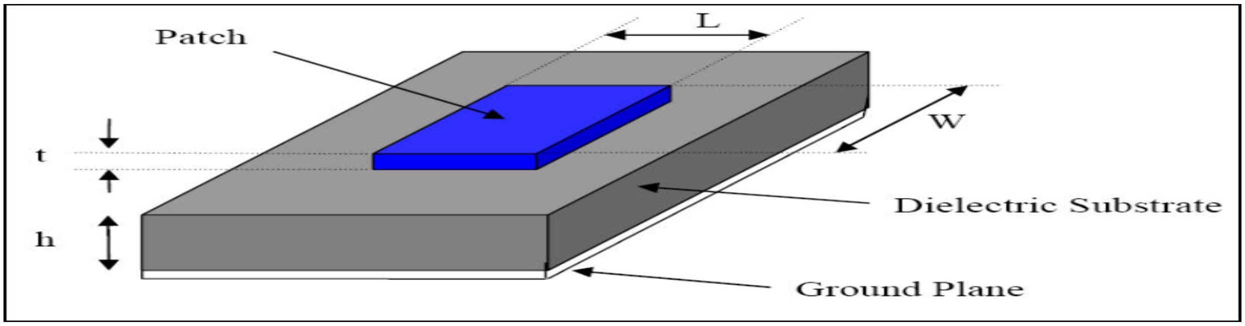


Fig 2.3: Structure of a Micro strip Patch Antenna

The following figure shows a patch antenna in its basic architecture. The patch and the ground plane are separated by a dielectric material. A flat plate over a ground plane and then the dielectric substrate at the center and the patch is at the top. The patch and the ground plane are generally conducting materials such as gold, copper and the patch can be any shape as the design specification. The feed line is used to feed the patch. There are many different types of feeding techniques. Usually, the patch and the feed line are photo etched to the substrate.

The radiating patch can be square, rectangular, circular, triangular, elliptical, circular ring and dipole and so on.

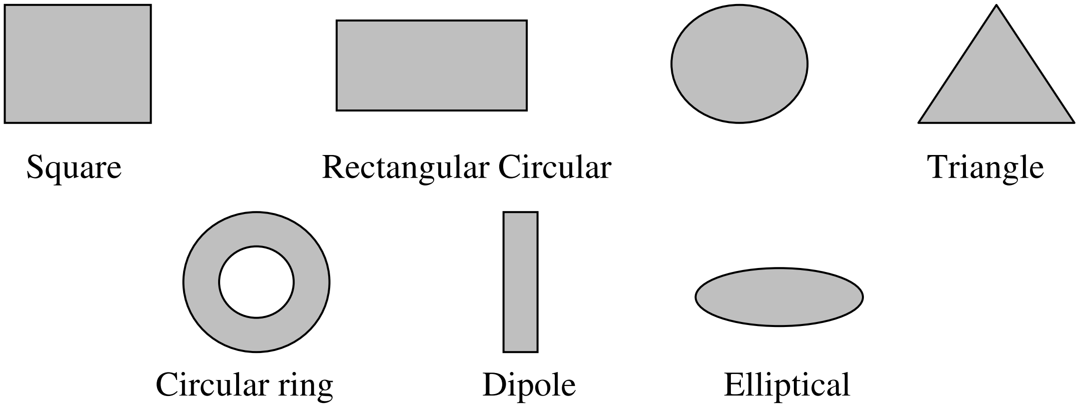


Fig 2.4: Common shapes of micro strip patch elements.

2.6 ADVANTAGE AND DISADVANTAGE OF PATCH ANTENNA

Microstrip Patch antennas are widely used in today’s era. It is used in satellite communication, military purposes, GPS, mobile, missile systems etc as due to its compact shape and light weight, les complexity and easy to implement. Some of its advantages and disadvantages in the book by Waterhouse (2003) are as follows are given below.

A) **Advantage:**

- Easy of manufacturing
- It has a very low fabrication cost
- Microstrip patch antenna is efficient radiator.
- It has a support for both linear and circular polarization
- Easy in integration with microwave integration circuit

B) **Disadvantage:**

- Low impedance bandwidth
- Low Gain
- Extra radiation occurs from its feed and junctions
- Excitation of surface wave
- Size of micro strip antenna comes in both advantage and disadvantage but there are some application where the micro strip antenna size is too large to be used.

2.7 APPLICATIONS

The microstrip patch antennas are famous for their performance and robust design. Microstrip patch antennas have applications in various fields such as in the medical field, satellites and even in the military systems just like in the rockets, aircrafts missiles and many more. Now they are booming in the commercial aspects due to their low cost of the substrate material and the fabrication. Microstrip patch antenna has a number of applications. Some of these applications are discussed as

- **Mobile and satellite communication application:** Mobile communication requires small, low profile, low cost antennas. Microstrip patch antenna meets all the necessities and a number of microstrip antennas have been designed for use in mobile communication systems.
- **Global positioning system applications:** Microstrip patch antennas having high permittivity sintered substrate material for global positioning system (GPS). These antennas are circularly polarized, very compact
- **Radio frequency identification (RFID)**: RFID is used in different areas like mobile communication, logistics, manufacturing, transportation and health care. RFID system

generally uses frequencies between 30 Hz and 5.8 GHz depending on its applications. Basically RFID system is a tag or transponder and a transceiver or reader.

- **Reduced size microstrip patch antenna for Bluetooth applications:** In this, the microstrip antenna operates in the 2400 to 2484 MHz ISM Band. Although an air substrate is introduced, microstrip antenna occupies a small volume of 33.3×6.6×0.8.
- **Interoperability for microwave access (WiMax):** The IEEE 802.16 standard is known as WiMax. It can reach upto 30 mile radius theoretically and data rate 70 Mbps. Microstrip patch antenna generates three resonant modes at 2.7, 3.3 and 5.3 GHz and can, therefore, be used in WiMax compliant communication equipment. In the wireless communication, networking, aerospace & defense industries. For WiMAX, LTE, multi-gigabit per second data links, radar, & satellite applications, ADS provides full, standards-based design and verification with Wireless Libraries and circuit-system-EM co-simulation in an integrated platform.
- **Broadband microstrip S-shaped patch antenna for wireless communication**: This is a single-patch broadband microstrip S-shaped patch antenna. Microstrip S-shaped patch antenna is fed by a coaxial feeding. The antenna is designed by inserting two slots into rotated square patch then it look like English letter ‘S’. Because of the slots and thick substrate, bandwidth of antenna is increased.
- **Radar application:** Radar can be used for detecting moving targets such as people and vehicles. The microstrip antennas are an ideal choice. The fabrication technology based on photolithography enables the bulk production of microstrip antenna with repeatable performance at a lower cost in a lesser time frame as compared to the conventional antennas.

Feeding method of the patch Antenna

2.8 FEED TECHNIQUES

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories- contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).

2.8.1 Coaxial Feed

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure 3.1, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane.

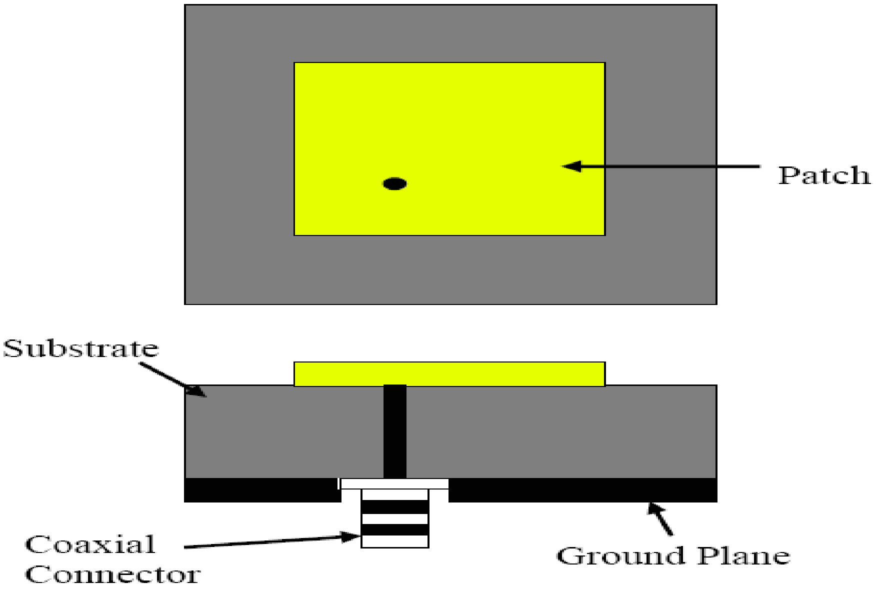


Fig 2.5: Probe fed Rectangular Microstrip Patch Antenna

The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, a major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda o$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems.

2.8.2 Aperture Coupled Feed

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 3.2. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane

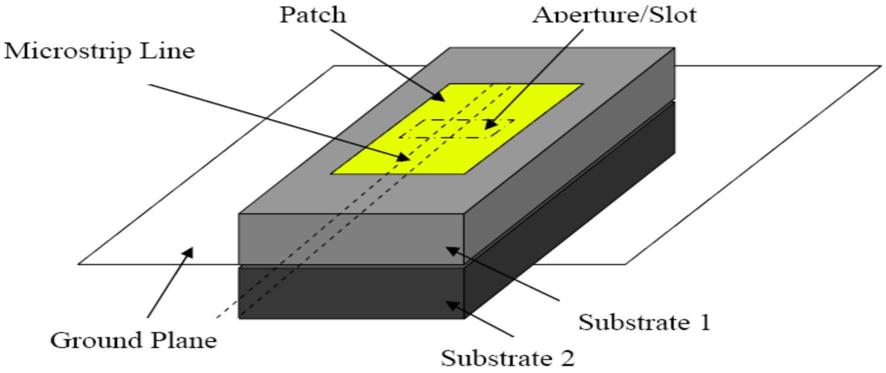


Fig 2.6: Aperture-coupled feed

The coupling aperture is usually centered under the patch, leading to lower cross polarization due to symmetry of the configuration.

2.8.3 Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Fig2.7 , two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%), due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances.

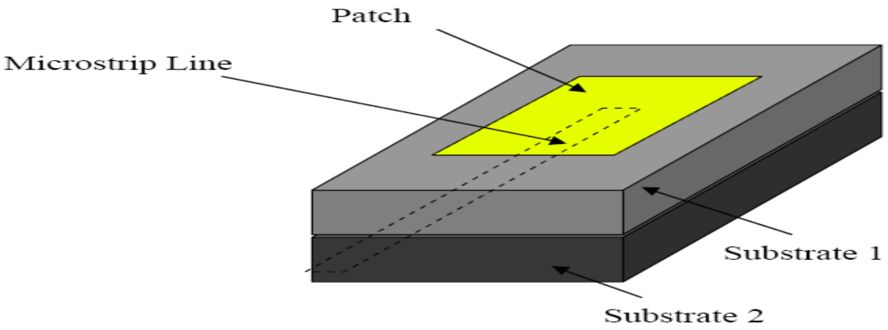


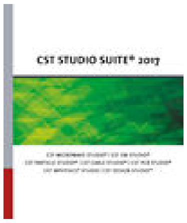
Fig 2.7 Proximity-coupled Feed

Matching can be achieved by controlling the length of the feed line and the width to- line ratio of the patch. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the antenna.

Chapter 3
Methodology

3.1 INTRODUCTION

A patch antenna (also known as a rectangular micro strip antenna) is types of radio antenna with allow profile, which can be mounted on a flat surface. It consist of flat rectangular sheet Or "patch" of metal, mounted over a larger sheet of metal called Ground plan. The assembly is usually contained inside a plastic redone, which protects the antenna structure from damage .Patch antennas are simple to fabricate and easy to modify and customize. They two metal sheets together from a resonant piece of micro strip transmission line with a length of approximately one-half wavelength of the radio waves. A patch antenna is usually constructed on a dielectric substrate, using the same materials to make printed circuit board.



3.2 CST STUDIO SUITE

The electromagnetic simulation software CST STUDIO SUITE is the culmination of many years of research and development into the most accurate and efficient computational solutions for electromagnetic designs. It comprises CST's tools for the design and optimization of devices operating in a wide range of frequencies - static to optical. Analyses may include thermal and mechanical effects, as well as circuit simulation.

CST STUDIO SUITE benefits from an integrated design environment which gives access to the entire range of solver technology. System assembly and modeling facilitates multi-physics and co-simulation as well as the management of entire electromagnetic systems.CST STUDIO SUITE can offer considerable product to market advantages such as shorter development cycles, virtual prototyping before physical trials, and optimization instead of experimentation.

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3.3 CST STUDIO SUITE COMPRISES THE FOLLOWING MODULES

1. CST MICROWAVE STUDIO(CST MWS): is the leading edge tool for the fast and accurate 3D simulation of high frequency devices and market leader in Time Domain simulation. It enables the fast and accurate analysis of antennas, filters, couplers, planar and multi-layer structures and SI and EMC effects etc.
2. CST EM STUDIO (CST EMS): is an easy-to-use tool for the design and analysis of static and low frequency EM applications such as motors, sensors, actuators, transformers, and shielding enclosures.
3. CST PARTICLE STUDIO (CST PS): has been developed for the fully consistent simulation of free moving charged particles. Applications include electron guns, cathode ray tubes, magnetrons, and wake fields.
4. CST CABLE STUDIO (CST CS): for the simulation of signal integrity and EMC/EMI analysis of cable harnesses.
5. CST PCB STUDIO (CST PCBS): for the simulation of signal integrity and EMC/EMI EMI on printed circuit boards.
6. CST MPHYSICS STUDIO (CST MPS): for thermal and mechanical stress analysis.
7. CST DESIGN STUDIO (CST DS): is a versatile tool that facilitates 3D EM/circuit co-simulation and synthesis

3.4 SOLVER TECHNOLOGIES:

1. **High frequency:**
   - Transient solver – general purpose
   - Frequency domain solver – general purpose
   - Integral equation solver – electrically large structures, RCS
   - Asymptotic solver – installed performance, RCS
   - Eigen mode solver – resonant cavities
   - Multilayer solver – planar structures
   - Filter Designer 2D – RF filter analysis and synthesis
   - Filter Designer 3D – cross-coupled cavity filter synthesis

2. **Low frequency:**
   - Electrostatic / Magneto static – fast static simulation
   - Stationary current solver – DC applications
   - Time domain solver – non-linear materials, transient effects
   - Frequency domain solver – eddy currents, displacement current

3. **EDA:**
   - PEEC solver – boards without reference planes
   - Transmission line solver – signal integrity
   - 3D FEFD solver – power integrity
   - Rule Check – EMC and SI on PCB

4. **Particle dynamics:**
    - Particle tracking solver – low energy particles, electron guns
    - PIC solver – high energy particles, RF devices
    - Wake field solver – accelerator components

5. **Multiphysics:**
    - Thermal solvers – electromagnetic heating, bio heat
    - Structural mechanics solver – thermal expansion, deformation

6. **EMC:**
    - Transmission line matrix (TLM) solver – general purpose, EMC
    - Cable solver – cable harness simulation
    - Rule Check – EMC and SI on PCBs.

3.5 DESIGN PROCEDURE OF RECTANGULAR PATCH ANTENNA:

To design a Rectangular patch antenna. There are four essential parameters which are important to know:-

- The operating frequency($f_\circ$).
- Dielectric constant of substrate (εr).
- The height of the dielectric substrate(h).
- The height of the conductor(t).

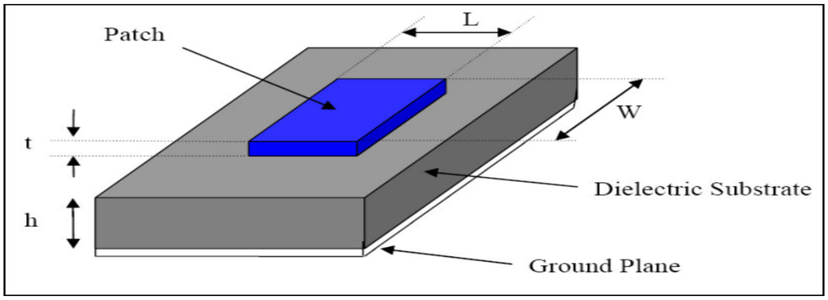


Fig 3.1: Rectangular Microstrip Patch Antenna

The other parameters:

- The width of the patch(W)
- The length of the patch(L)
- The width and length of the Ground plane and the substrate (Wg)(Lg).

3.6 METHODS OF ANALYSIS MICROSTRIP PATCH ANTENNA:

There are a lot of methods for analysis microstrip patch antenna:

- **The Transmission Line model:** Transmission line method is the easiest method as compared to the rest of the methods. This method represents the rectangular microstrip antenna as an array of two radiating slots, separated by a low impedance transmission line of certain length.

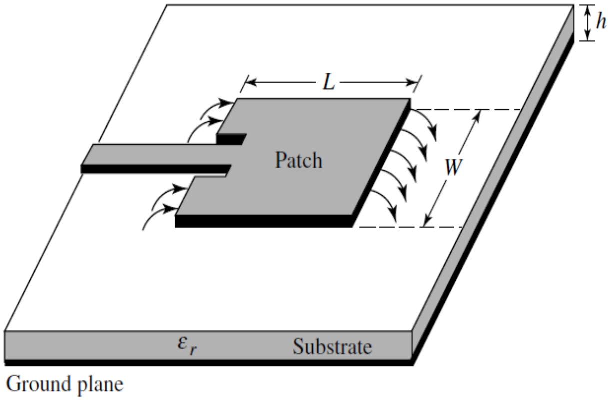


Fig 3.2: (a) Microstrip feed line

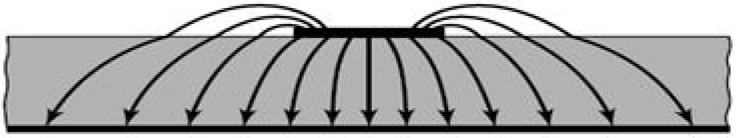


Fig 3.2:(b) Electric field line

- **The Cavity model:**

  Another model available at our disposal in order to analyze microstrip antennas is the cavity model. This model is different from transmission line model as in it is provides a better way to model the radiation patterns and is closer in the physical interpretation of the antenna characteristics. The normalized fields within the dielectric can be found more accurately by treating the region as a cavity bounded by electric conductors (above and below) and by magnetic walls along the perimeter of the patch. An attempt is made to present a physical interpretation into the formation of the fields within the cavity and radiation through its side walls.

- **Method of Moments (MoM):**
  IE3D is a full-wave, method-of-moments based electromagnetic simulator solving the current distribution on 3D and multilayer structures of general shape. It has been widely used in the design of MMICs, RFICs, LTCC circuits, microwave/millimeter-wave circuits, IC interconnects and packages, HTS circuits, patch antennas, wire antennas, and other RF/wireless antennas.

Among this 3 model to design our microstrip patch antenna we are using the transmission line model and here is the equation of Transmission line

3.7 THE TRANSMISSION LINE EQUATIONS:

1) To find Width (W) :

$$W = \frac{c}{2 f_\circ \sqrt{\frac{(\varepsilon r+1)}{2}}} \tag{4}$$

2) TO FIND THE EFFECTIVE DIELECTRIC CONSTANT:

$$\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left(1+12\,\frac{h}{W}\right)^{-1/2} \tag{5}$$

3) TO FIND THE EFFECTIVE LENGTH:

$$L_{eff} = \frac{c}{2 f_\circ \sqrt{\varepsilon reff}} \tag{6}$$

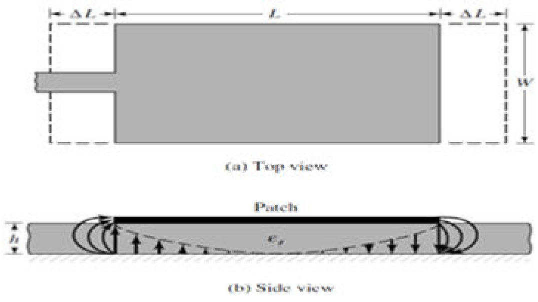


Fig 3.3: Physical and effective lengths of microstrip patch antenna

4) TO FIND THE FRINGING LENGTH (ΔL) :

$$\Delta L = 0.412\, h \frac{(\varepsilon reff+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon reff-0.258)\left(\frac{W}{h}-0.8\right)} \qquad (7)$$

5) To find the actual length L and the width and length of the Ground :

$$L = L_{eff} - 2\Delta L \qquad (8)$$

1) Lg=2∗L 2)Wg=2*W

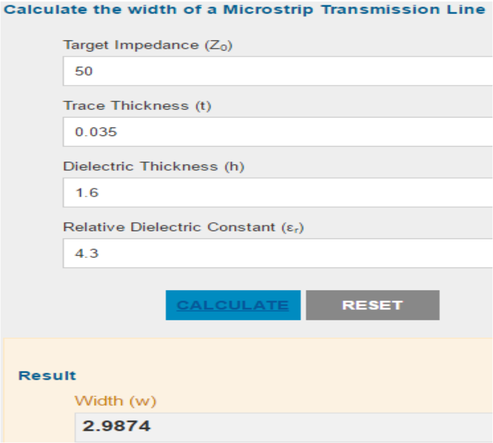
6) The length of inset (Fi) :

Fi= 10^4*.001699∗εr7+0.13761∗εr6−6.1783∗εr5+93.187∗εr4−682.69 ∗εr3.... (9)

7) The feed line width of (Wf) :

$$w = \frac{7.48 \times h}{e^{\left(Z_0 \frac{\sqrt{\varepsilon_r+1.41}}{87}\right)}} - 1.25 \times t \qquad (10)$$

or using transmission line software, we can also get the value for an Example:



Calculate the width of a Microstrip Transmission Line

Target Impedance (Z_0): 50

Trace Thickness (t): 0.035

Dielectric Thickness (h): 1.6

Relative Dielectric Constant (ε_r): 4.3

Result

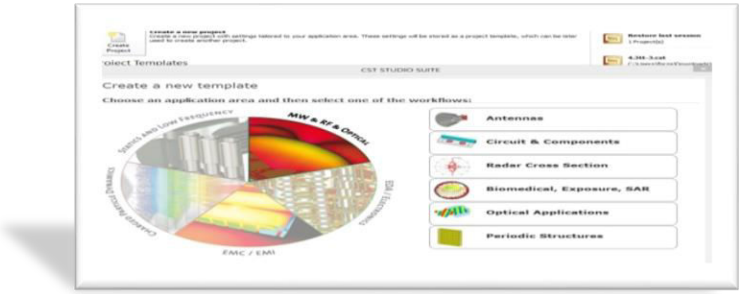
Width (w): 2.9874

Fig 3.4: Width of the microstrip line

For design a microstrip patch antenna with the microstrip feed line (inset-fed) works on(min frequency) 3.1-4.9 GHZ (max frequency) the parameter chart with different type Dielectric constant substrate (FR-4 (lossy), Rogers RO4350 (lossy) , Rogers RT5880 (lossy) with different calculated width and length

Parameter Name	FR-lossy ε_r (4.3)	Rogers RO4350 ε_r (3.66)	Rogers RT5880 (ε_r=2.2)
Width (w)	26	28	33
Length (l)	20	21	28
feed line width (wf)	2.9874	3.2373	3.9722
gap-patch and feed (gpf)	1	1	1
Ground length (lg)	2*l	2*l	2*l
Ground width(wg)	2*w	2*w	2*w
Height-conductor(ht)	0.035	0.035	0.035
Substrate (hs)	1.6	1.6	1.6

So this is the parameter list and we already discussed about the formulas, now the designing process is given below. So to design the antenna we are using the CST software In Fig 3.5, 3.6, and 3.7 shown the step by step procedure.



Create a new template

Choose an application area and then select one of the workflows:

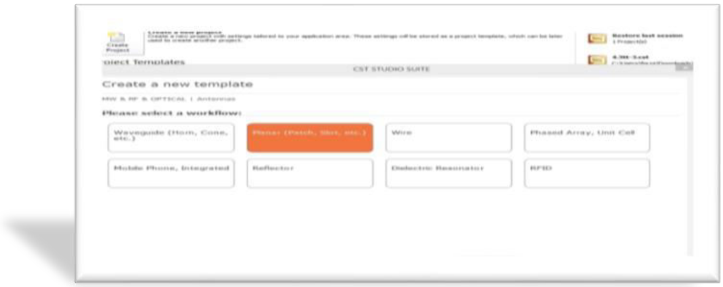
Fig 3.5: CST Option

1) At first open the CST studio suite then create a new template

2) After clicking the new project have to choose an application area which is MW& OPTICAL and Antennas then have to select the workflows ours one is (Planar, patch, slot, etc)

3) After click on planar have choose again which solver we need for our antenna (Time Domain solver)

4) Then we have to define the minimum and maximum frequency and also select which radiation pattern we want to monitor

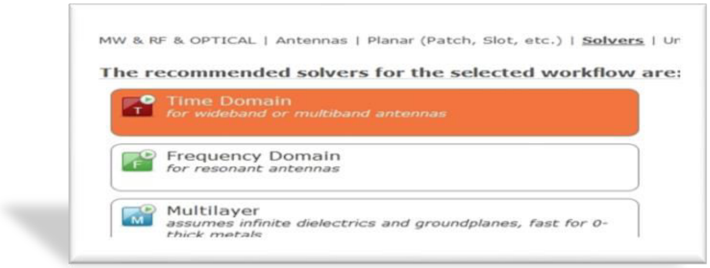


Create a new template

MW & RF & OPTICAL | Antennas

Please select a workflow:

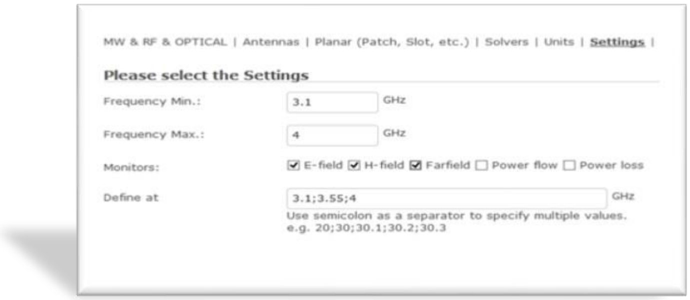
Fig 3.6 CST Option



MW & RF & OPTICAL | Antennas | Planar (Patch, Slot, etc.) | Solvers | Ur

The recommended solvers for the selected workflow are:

Fig 3.7 CST Option


MW & RF & OPTICAL | Antennas | Planar (Patch, Slot, etc.) | Solvers | Units | Settings |

Please select the Settings

Frequency Min.: 3.1 GHz

Frequency Max.: 4 GHz

Monitors: ☑ E-field ☑ H-field ☑ Farfield ☐ Power flow ☐ Power loss

Define at 3.1;3.55;4 GHz

Use semicolon as a separator to specify multiple values.
e.g. 20;30;30.1;30.2;30.3

Fig 3.8 CST Option

After finishing this setting a new window will come, where we have to design the antenna.

There is a tool bar and this option is available:

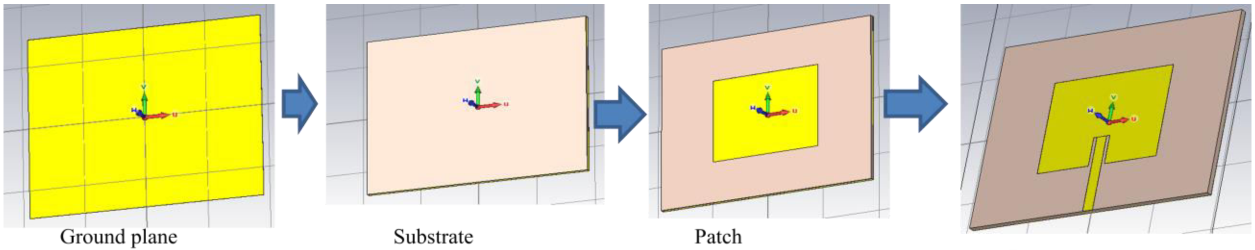
- Home
- Modeling
- Simulation
- post processing
- view

3.8 PARTS DESIGNING OF AN ANTENNA

To design ground plane of an antenna at first click on modeling then click on brick, we choose brick because we are designing a rectangular shape antenna, the other shapes like (cone, circular sphere) are also available. now select the brick then press ESC, a box will come which contain the width ,length , height and material for ground plane we are using copper, to design a substrate same procedure was used but the material of a substrate is FR-4 (lossy),

Using this same procedure and applying the formula we designed the rest of the part like designed the patch where material is copper , empty space for inset feed where the material is nickel , after the empty space we designed the inset feed line where the material is copper then to add the patch and feed into one object we used the Boolean method to add this lastly we have create a wave guide port using the CST solver so our antenna is ready to simulate

In Fig 3.9 shows the different parts of an antenna ground, substrate, patch, empty space and feed line



Ground plane

Substrate

Patch

Empty space
& feedline

Fig 3.9: Different parts of an antenna

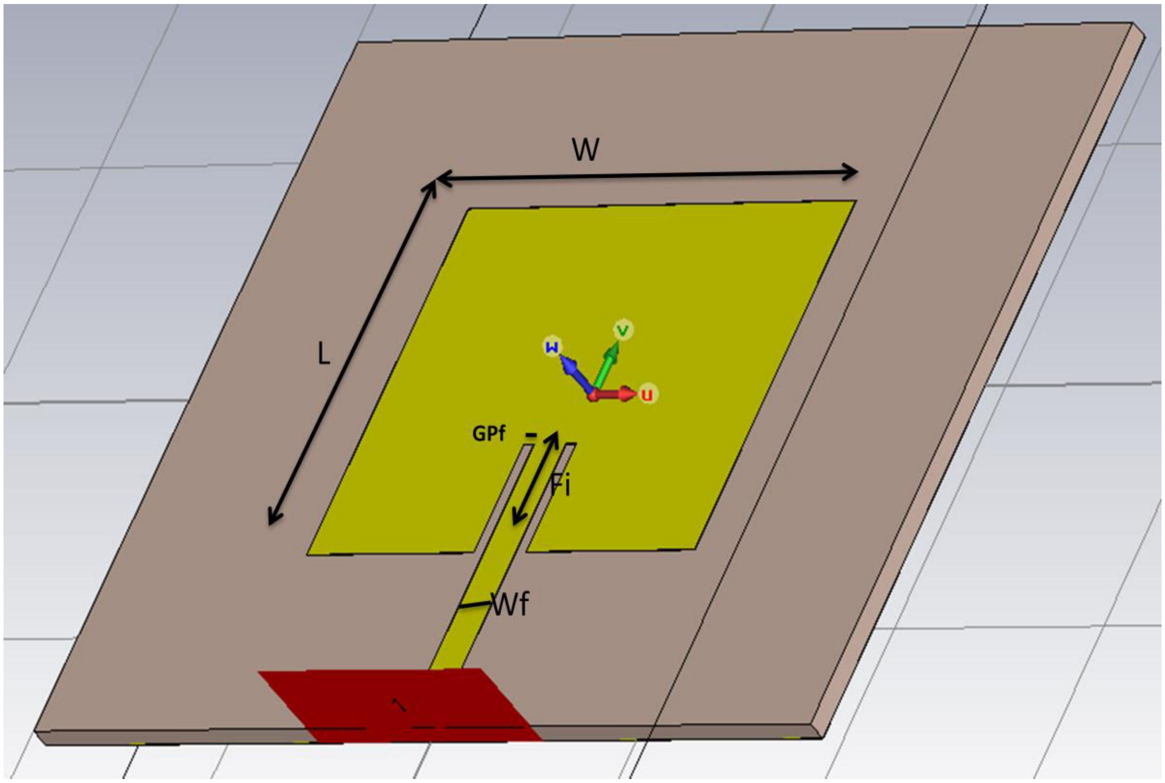
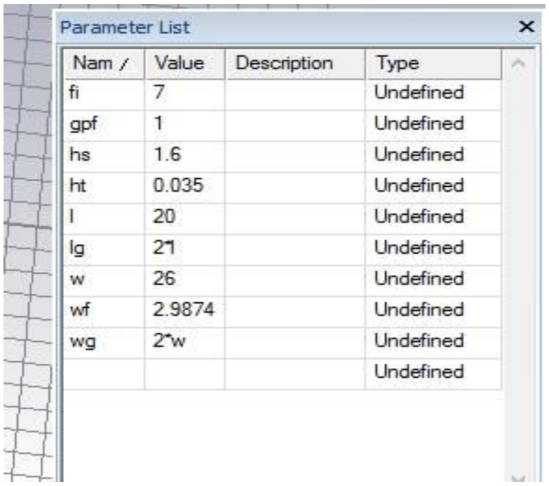


Fig 3.10: Complete patch antenna

So In Fig 3.10: this the complete patch antenna with labeling in 3D view where Gpf means (gap between patch and inset feed) and Wf (width of the feed line) and Fi means (length of the inset feed)


Parameter List

Nam /	Value	Description	Type
fi	7		Undefined
gpf	1		Undefined
hs	1.6		Undefined
ht	0.035		Undefined
l	20		Undefined
lg	21		Undefined
w	26		Undefined
wf	2.9874		Undefined
wg	2*w		Undefined
			Undefined

Fig 3.11: parameter list

CHAPTER 4

Results and discussion

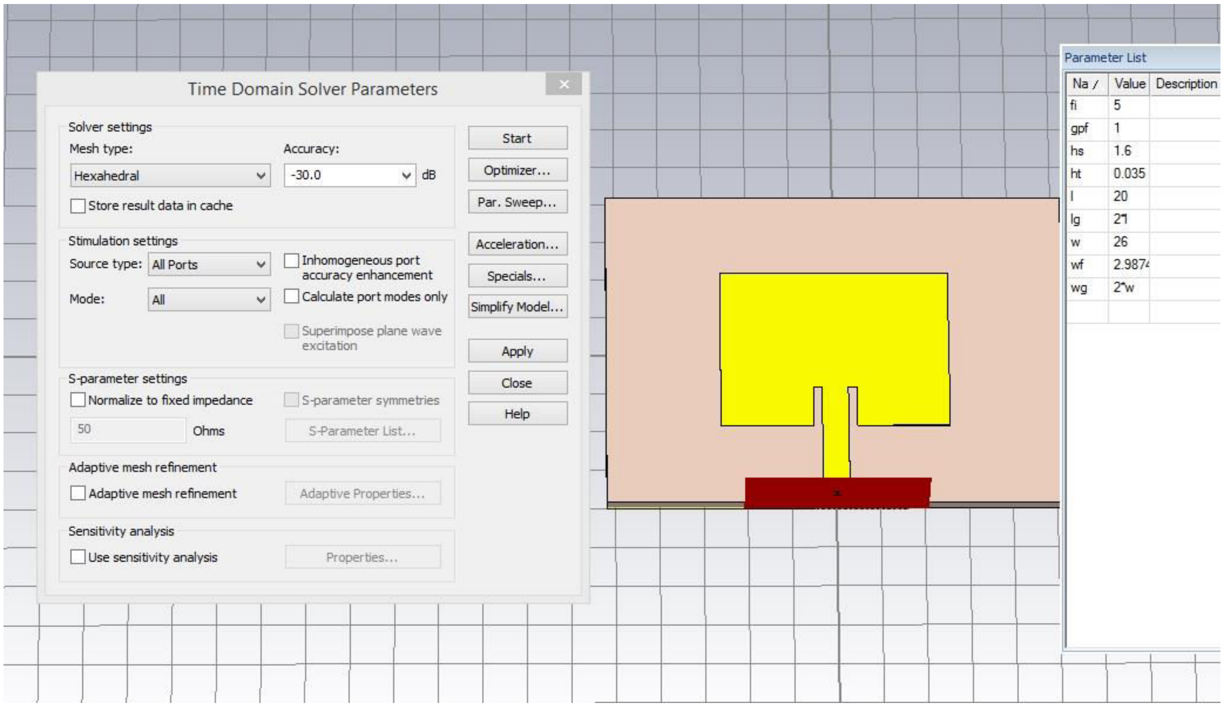
4.1 ANALYSIS OF OUR DESIGHNED ANTENNA

After successfully design the antenna in CST studio suite , Now it's time for the simulation part where we can check the bandwidth through "S-parameter" , can also check the Gain, Realized Gain , Far-field, H-field, Balance, Efficiency, VSWR (voltage Standing Wave Ratio).

So we were simulated our antenna through Time Domain Solver Parameter , in fig 4.1 the solver setting is given for our antenna and in fig 4.2 successfully simulated message for our antenna.

Solver Setting Contain:

- Mesh type
- Accuracy
- Normalize to fixed impedance
- sensitivity analysis
- types of mode



Time Domain Solver Parameters

Solver settings

Mesh type: Hexahedral

Accuracy: -30.0 dB

☐ Store result data in cache

Stimulation settings

Source type: All Ports

Mode: All

☐ Inhomogeneous port accuracy enhancement

☐ Calculate port modes only

☐ Superimpose plane wave excitation

S-parameter settings

☐ Normalize to fixed impedance

50 Ohms

☐ S-parameter symmetries

Adaptive mesh refinement

☐ Adaptive mesh refinement

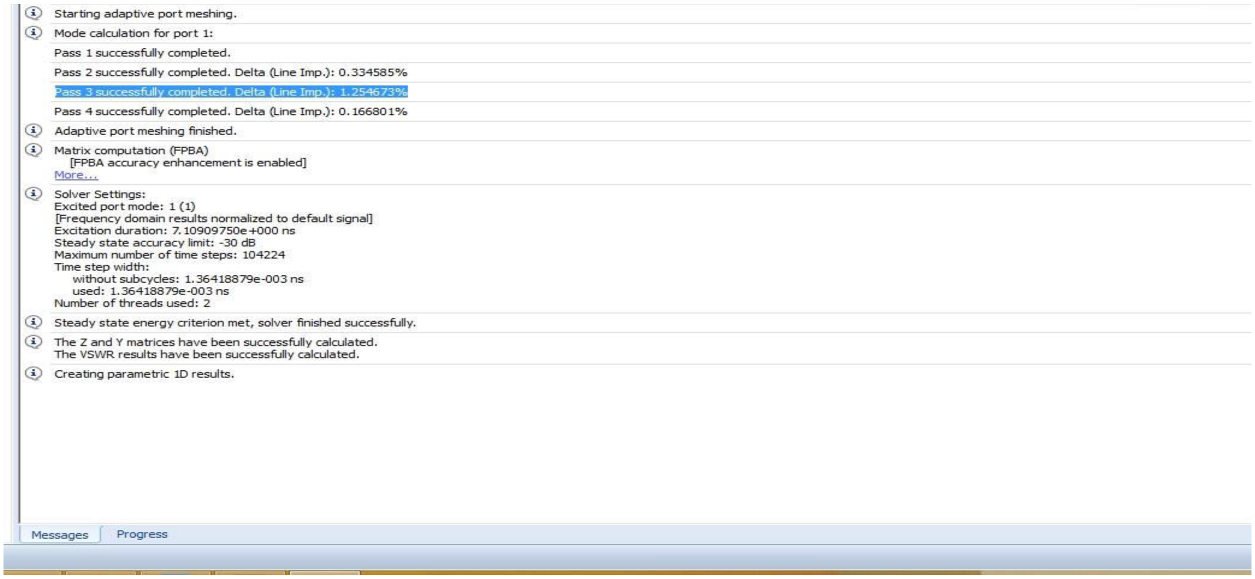
Sensitivity analysis

☐ Use sensitivity analysis

Parameter List

Na /	Value	Description
fi	5	
gpf	1	
hs	1.6	
ht	0.035	
l	20	
lg	21	
w	26	
wf	2.987	
wg	2*w	

Fig 4.1: Time domain solver parameter



```
Starting adaptive port meshing.
Mode calculation for port 1:
Pass 1 successfully completed.
Pass 2 successfully completed. Delta (Line Imp.): 0.334585%
Pass 3 successfully completed. Delta (Line Imp.): 1.254673%
Pass 4 successfully completed. Delta (Line Imp.): 0.166801%
Adaptive port meshing finished.
Matrix computation (FPBA)
    [FPBA accuracy enhancement is enabled]
More...
Solver Settings:
Excited port mode: 1 (1)
[Frequency domain results normalized to default signal]
Excitation duration: 7.10909750e+000 ns
Steady state accuracy limit: -30 dB
Maximum number of time steps: 104224
Time step width:
    without subcycles: 1.36418879e-003 ns
    used: 1.36418879e-003 ns
Number of threads used: 2
Steady state energy criterion met, solver finished successfully.
The Z and Y matrices have been successfully calculated.
The VSWR results have been successfully calculated.
Creating parametric 1D results.
```

Fig 4.2: successful simulated message

4.2 S-PARAMETER:

S-parameter describes the input-output relationship between ports (or terminals) in an electrical system. For instance, if we have 2 ports (intelligently called Port 1 and Port 2), then S12 represents the power transferred from Port 2 to Port 1. S21 represents the power transferred from Port 1 to Port 2. In general, SNM represents the power transferred from Port M to Port N in a multi-port network. That in general S-parameters are a function of frequency (i.e. vary with frequency).

Basically we designed three miscrostrip patch antenna using different types material (FR-4 (lossy), Rogers RO4350 (lossy), Rogers RT5880 (lossy)).

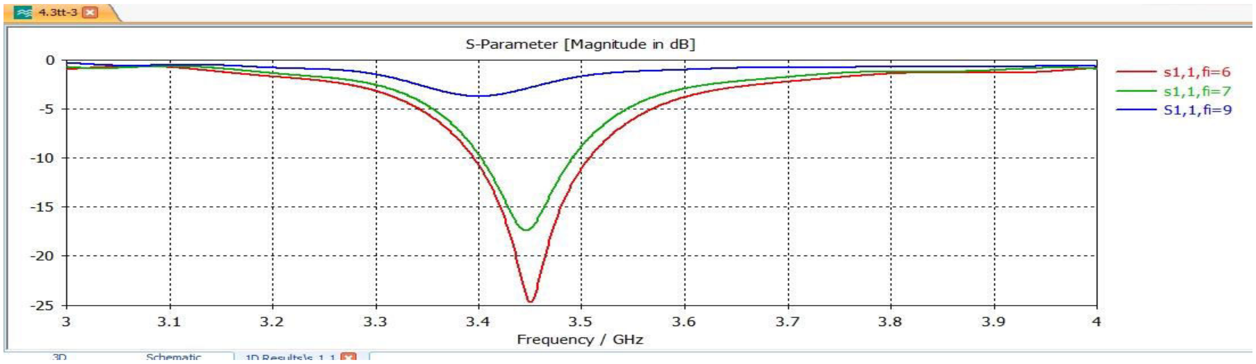


Fig 4.1: Material FR-4(lossy)

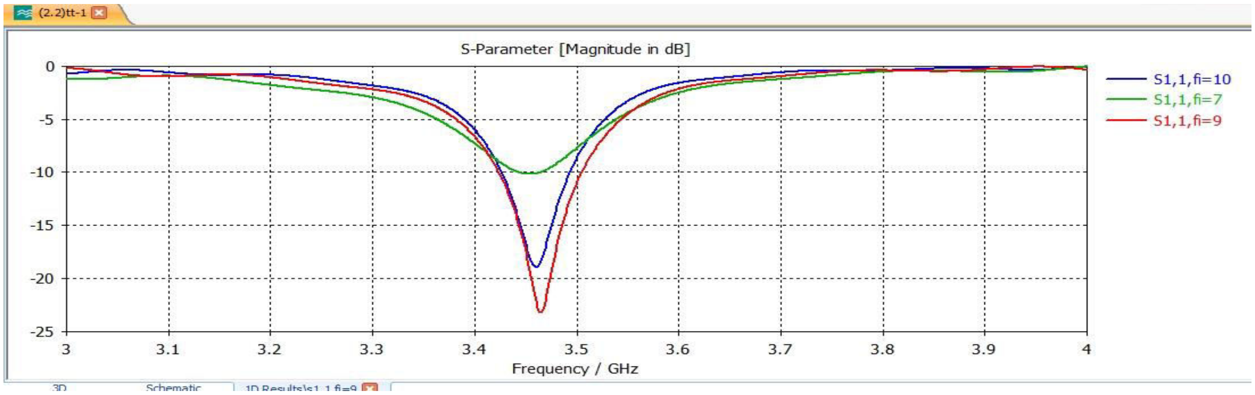


Fig 4.3: Material Rogers RT5880 (lossy)

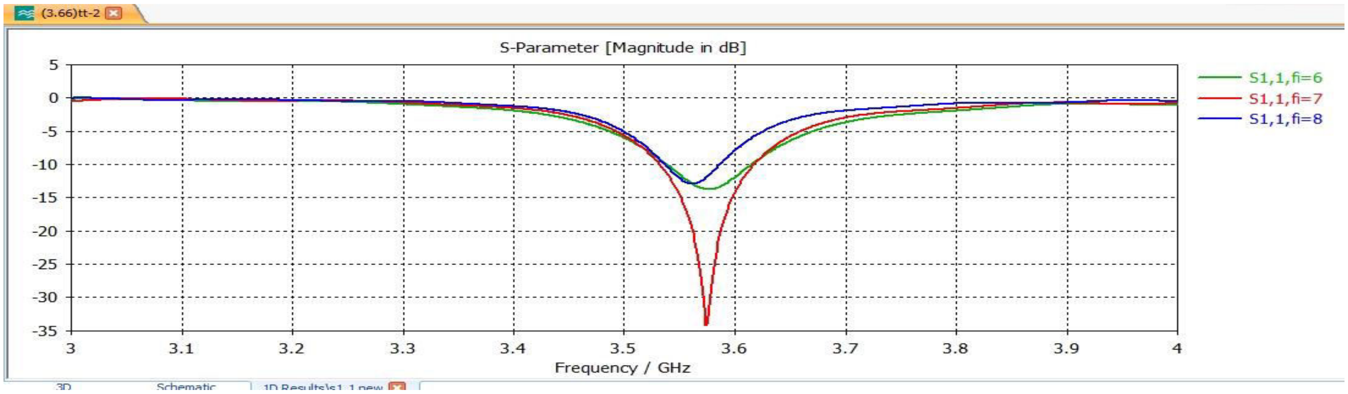


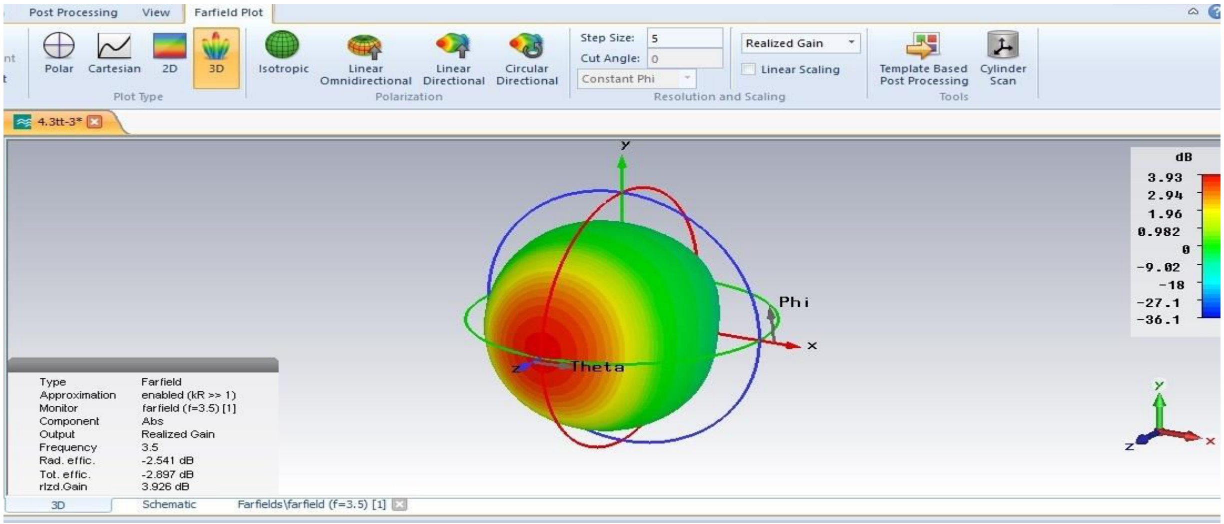
Fig 4.4: Material Rogers RO4350 (lossy)

Basically the curves indicate the return loss of the designed antenna and we can also find out the band width with the help of this curve. Changing the length of the inset feed we found this three curve, for an example when the length of the inset feed is 7 the red curve is shown , when 6 the green curve shown ,when 8 the blue curve is shown .

4.3 FAR FIELD RADIATION

The far field is the region far from the antenna, as you might suspect. In this region, the radiation pattern does not change shape with distance (although the fields still die off as 1/R, the power density dies off as 1/R^2). Also, this region is dominated by radiated fields, with the E- and H-fields orthogonal to each other and the direction of propagation as with plane waves.

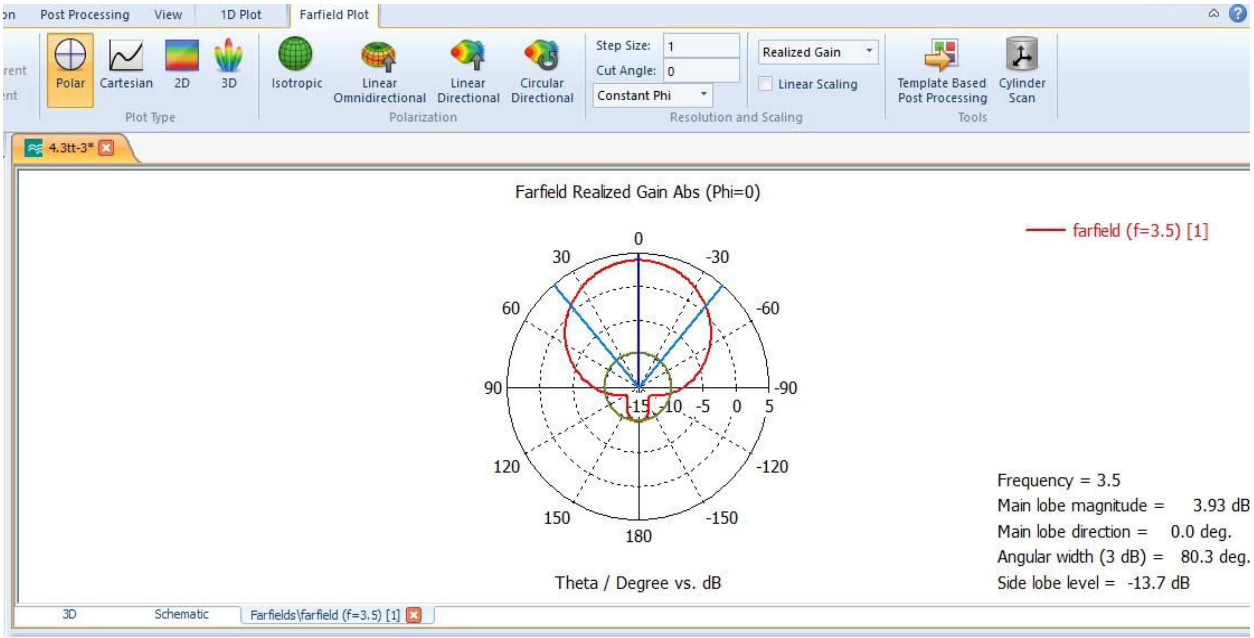
4.4 FAR FIELD RADIATION PATTERN IN 3D FROM AND ALSO IN POLAR FORM :



Step Size: 5
Cut Angle: 0
Constant Phi
Realized Gain

Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=3.5) [1]
Component	Abs
Output	Realized Gain
Frequency	3.5
Rad. effic.	-2.541 dB
Tot. effic.	-2.897 dB
rlzd.Gain	3.926 dB

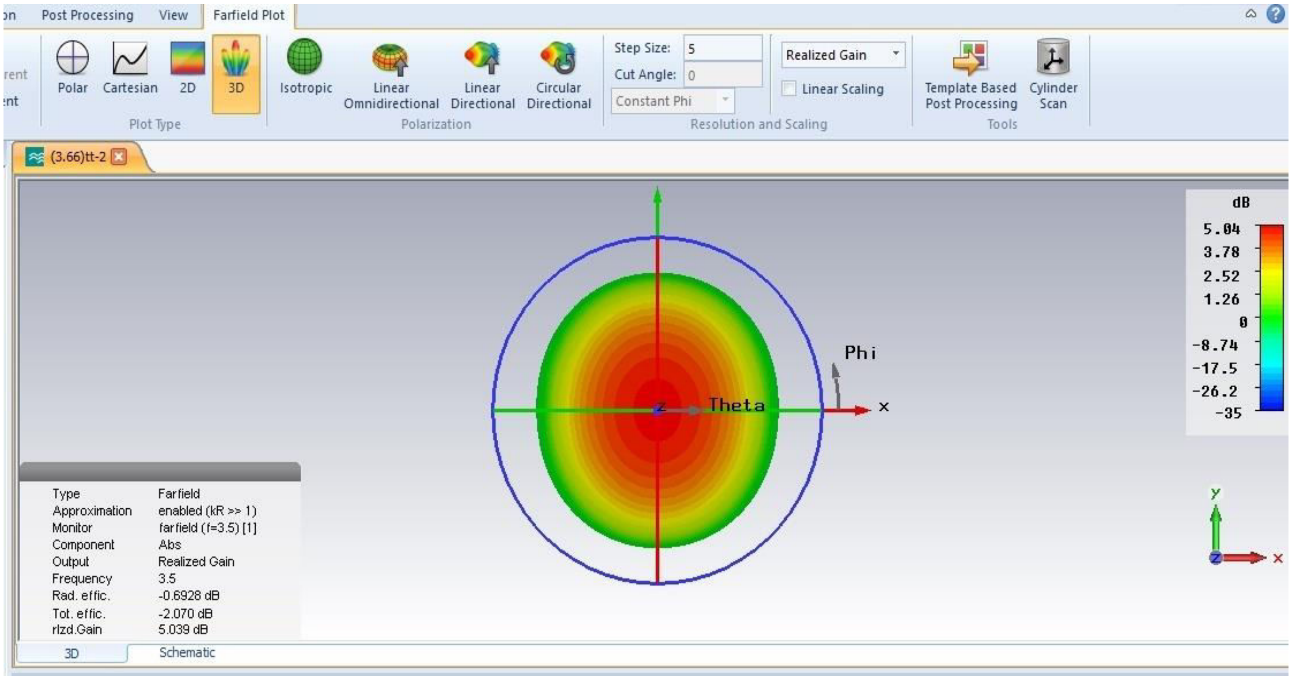
Fig 4.5: Far Field Radiation pattern in 3D form



Step Size: 1
Cut Angle: 0
Constant Phi
Realized Gain

Frequency = 3.5
Main lobe magnitude = 3.93 dB
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 80.3 deg.
Side lobe level = -13.7 dB

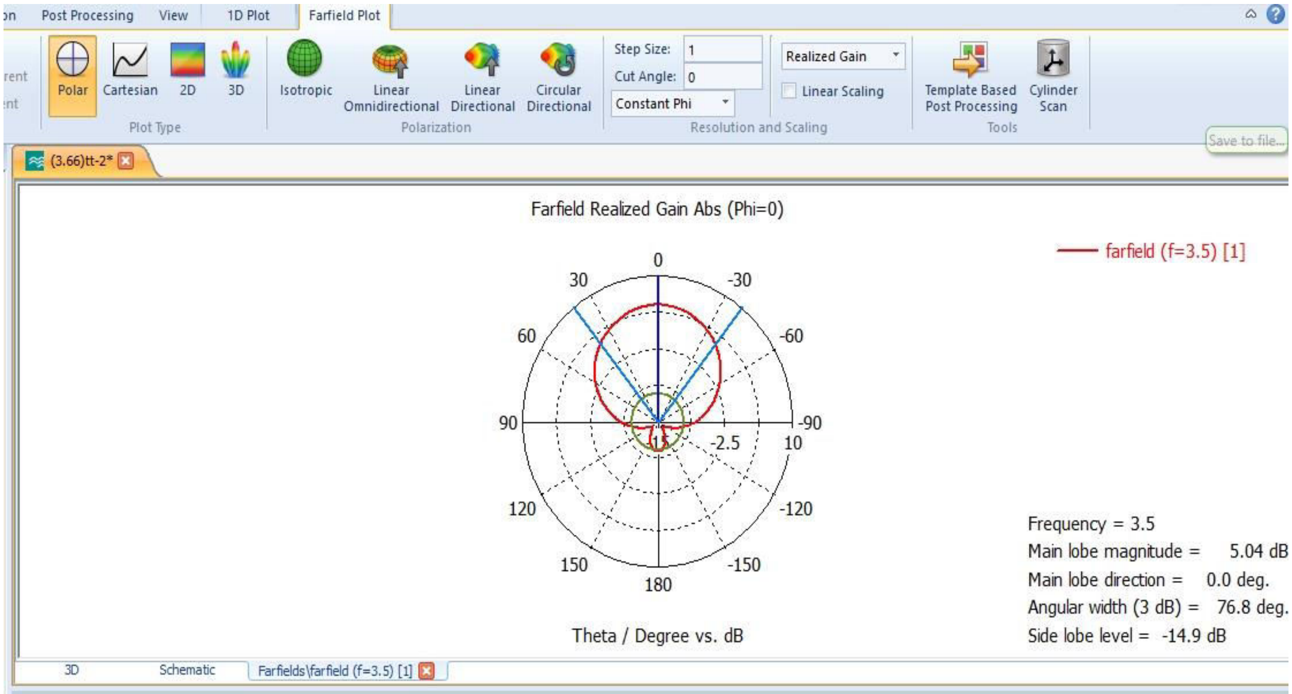
Fig 4.6: Far Field Radiation pattern Polar form



Step Size: 5
Cut Angle: 0
Constant Phi
Realized Gain
☐ Linear Scaling

Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=3.5) [1]
Component	Abs
Output	Realized Gain
Frequency	3.5
Rad. effic.	-0.6928 dB
Tot. effic.	-2.070 dB
rlzd.Gain	5.039 dB

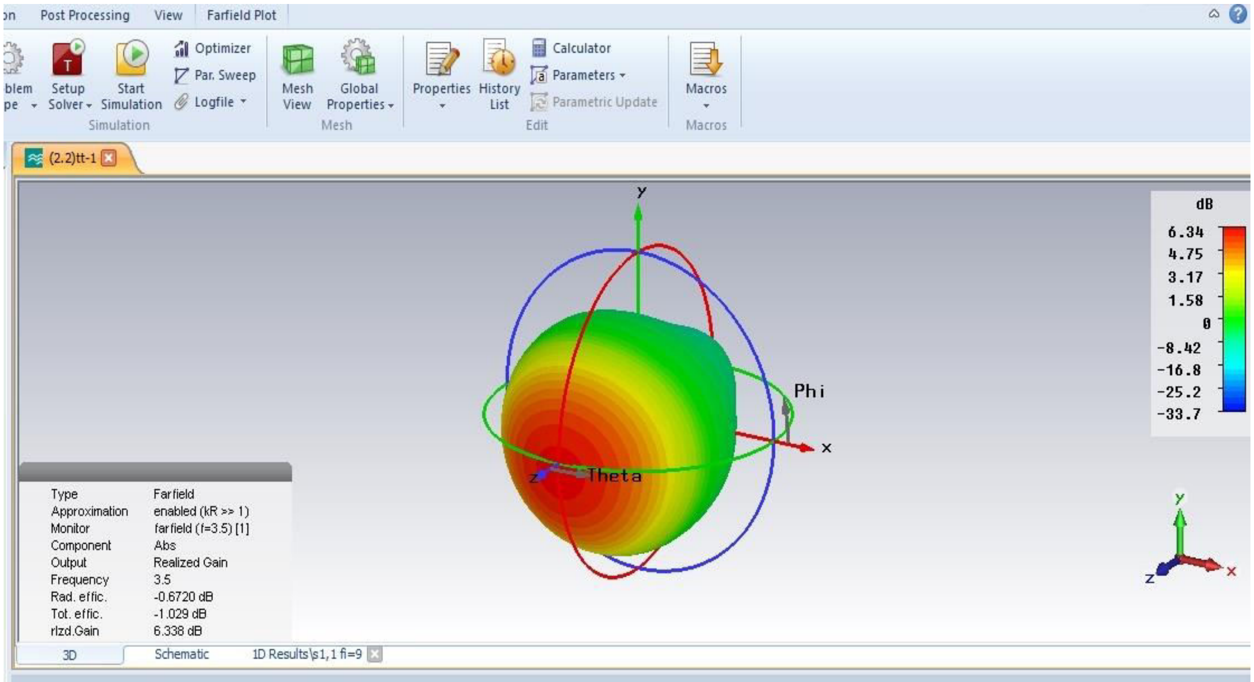
Fig 4.7**:** Far Field Radiation pattern in 3D form



Step Size: 1
Cut Angle: 0
Constant Phi
Realized Gain
☐ Linear Scaling

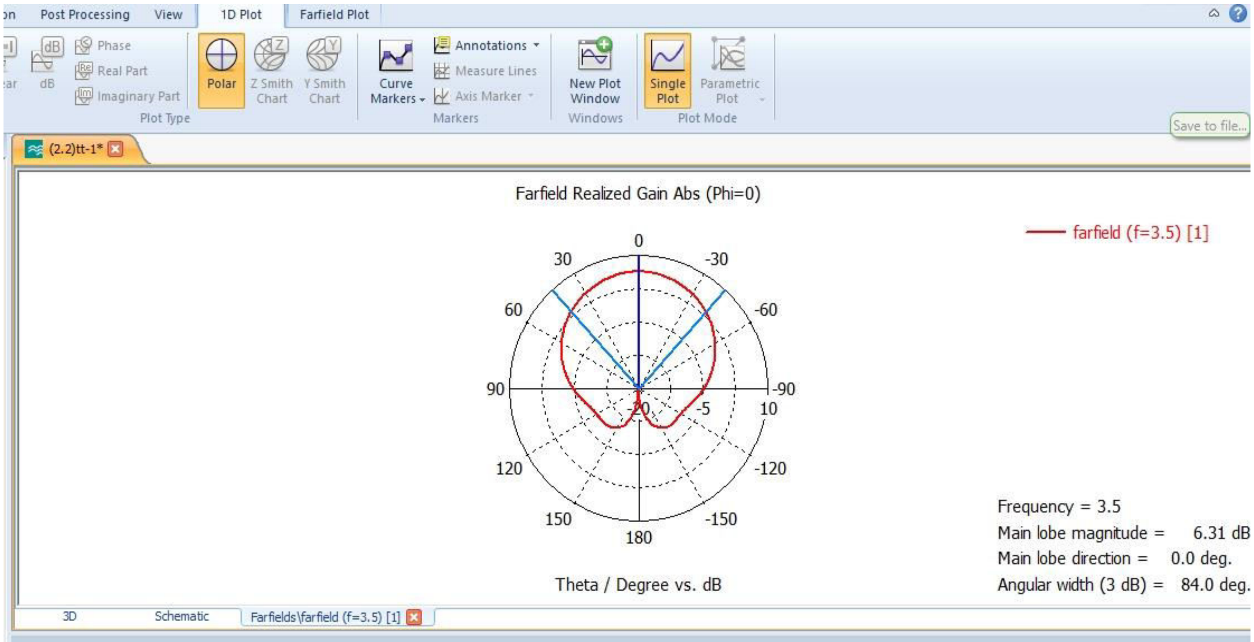
Frequency = 3.5
Main lobe magnitude = 5.04 dB
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 76.8 deg.
Side lobe level = -14.9 dB

Fig 4.8: **:** Far Field Radiation pattern in polar form



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=3.5) [1]
Component	Abs
Output	Realized Gain
Frequency	3.5
Rad. effic.	-0.6720 dB
Tot. effic.	-1.029 dB
rlzd.Gain	6.338 dB

Fig 4.9: Far Field Radiation pattern in 3D form



Frequency = 3.5
Main lobe magnitude = 6.31 dB
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 84.0 deg.

Fig 4.10: Far Field Radiation pattern in polar form

Table 4.1: Percentage bandwidth, return loss , realized gain for different inset-feed.(Material used FR-4 (lossy)

ε_r (4.3) FR-lossy	Width (mm)	Length (mm)	Inset-feed (mm)	BW(%) (-10 dB)	BW (MHZ)	Return loss (dB)	Realized Gain (dB)
	26	20	6	3.4%	117	-25	3.93
	26	20	7	2.8%	97.2	-17	3.58
	26	20	9	-	-	-4.5	-2.58

Table 4.2: Percentage bandwidth, return loss , realized gain for different inset-feed.

(Material used Rogers RO4350 (lossy))

ε_r (3.66) Rogers RO4350	Width (mm)	Length (mm)	Inset-feed (mm)	BW(%) (-10 dB)	BW (MHZ)	Return loss (dB)	Realized Gain (dB)
	28	21	6	2.1%	76	-15	5.142
	28	21	7	2.5%	87	-32	5.039
	28	21	8	1.2%	49	-13	4.77

Table 4.3: Percentage bandwidth, return loss, realized gain for different inset-feed. (Material used Rogers RT5880 (lossy)

Rogers RT5880 (ε_r =2.2)	Width (mm)	Length (mm)	Inset-feed (mm)	BW(%) (-10 dB)	BW (MHZ)	Return loss	Realized Gain (dB)
	33	28	7	1.1%	27	-10	6.00
	33	28	9	2.5%	83.1	-24	6.34
	33	28	10	1.2%	74.4	-19	5.8

In Table 4.4 we are collected some literature to compare our work. It is found that the volume of our antenna is the smallest among those in literatures [8-12]. We also found that some of our results like bandwidth is close to the best literature [12].

Table 4.4: Comparison of this work with literature

Width (mm)	Length (mm)	Height (mm)	Volume (mm^3)	BW(%) (-10dB)	Return loss	Reference
40	47	1.2	40×47×1.2 = 2256	1.87%	-30	*M.A Islam et al [8]*
26	40	1.6	26×40×1.6 = 1664	4.4%	-20	*Danish Hayat [9]*
49	53	1.67	49×53×1.67 = 4336	2.1%	-18	*Alaa A.Yassin [10]*
120	120	1.6	120×120×1.6 = 23040	5.7%	-29.2	*Piyaporn Krachodnok [11]*
25	24.9	3.2	25×24.9×3.2 =1992	3.94%	-26.52	*Ali El Alami [12]*
26	20	1.6	26×20×1.6 =832	3.4%	-25	Proposed Antenna

Therefore the main advantage of our proposed antenna is that the volume of the our proposed antenna is very compact with reasonable bandwidth.

CONCLUSION

In this paper, a simple rectangular microstrip patch antenna for application in 3.5 GHz frequency band is demonstrated and designed using CST Microwave Studio. This is operating in the frequency band of 3.1-3.9 GHz. The return loss at 3.5 GHz frequency is below -10 dB which shows that there is good matching at center frequency points. In our design, we used inset feed. The main advantage of this feeding technique is that this type of feeding can be given anywhere inside the patch which makes easier fabrication compared to other feeding technique

For better bandwidth, better VSWR, return loss, gain we used different materials like (FR-4, Rogers). It is found that with substrate FR-4 (ε_r=4.3) using the length of inset feed of 6 mm, we achieved the maximum percentage bandwidth of 3.4% and a return loss of -25 dB. The designed antenna is suitable for ultra wide band application.

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