# MINIATURIZED PATCH ANTENNA FOR UWB APPLICATIONS

*A Project report submitted in partial fulfillment of the requirements for*
*the award of the degree of*

**BACHELOR OF TECHNOLOGY**

**IN**

**ELECTRONICS AND COMMUNICATION ENGINEERING**

***Submitted by***

D. NIHARIKA (317126512016) K.KEERTHI PRATHYUSHA (317126512026)

P. SUDHAKAR (318126512L03) A.J.V. SAI TETA (318126512L09)

**Under the guidance of**
**Mr. Vijay Kumar Sahu M.tech(Ph.D)**
**Assistant Professor**
**Dept. of ECE**

**DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING**

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES
(UGC AUTONOMOUS)
(*Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC with 'A' Grade*)
Sangivalasa, bheemili mandal, visakhapatnam dist.(A.P)
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**ANITS**

# CERTIFICATE

*This is to certify that the project report entitled* **"MINIATURIZED PATCH ANTENNA FOR UWB APPLICATIONS"** submitted by **D.NIHARIKA (317126512016), K.KEERTHI PRATHYUSHA (317126512026), P.SUDHAKAR (318126512L03), A.J.V.SAI TEJA (318126512L09)** in partial fulfillment of the requirements for the award of the degree of **Bachelor of Technology** in **Electronics & Communication Engineering** of Andhra University, Visakhapatnam is a record of bonafide work carried out under my guidance and supervision.

**Project Guide**

**Mr.Vijay Kumar Sahu** M.Tech(Ph.D)
Assistant Professor
Department of E.C.E
ANITS

Assistant Professor
Department of E.C.E.
Anil Neerukonda
Institute of Technology & Sciences
Sangivalasa, Visakhapatnam-531 162

**Head of the Department**

**Dr.V.Rajyalakshmi**
Professor&HOD
Department of E.C.E
ANITS

Head of the Department
Department of E C E
Anil Neerukonda Institute of Technology & Sciences
Sangivalasa - 531 162

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**PROJECT STUDENTS**

**D. NIHARIKA (317126512016),**

**K.KEERTHI PRATHYUSHA (317126512026),**

**P. SUDHAKAR (318126512L03),**

**A.J.V. SAI TEJA (318126512L09)**

# ABSTRACT

Amidst the expeditious growth of communication technology, the demand for smaller antennas is advancing on a day-to-day basis. Technology to miniaturize the patch antenna is an important research topic that includes the use of specialized dielectric substrates, meandering techniques, shorting probes, etc. These methods might degrade the performance of the antenna designed. Hence, a new technique to adopt the new method to miniaturize the antenna. This involves the etching technology, which requires no extra effort in the fabrication of the antenna. Little efforts are required to ensure that the characteristics of the antenna are preserved while designing.

With the increasing popularity of UWB systems, there have been breakthroughs in the design of UWB antennas. Implementation of a UWB system is confronting numerous challenges and one of these challenges is to develop an appropriate antenna. This is because the antenna is a significant part of the UWB system and it affects the overall system’s performance. There are many approaches that help in obtaining the ultra-wideband, some of them include partial grounds, slots, round shapes, the use of dielectric resonator antennas, etc.

In the present work, a compact design of miniaturized microstrip Ultra Wide Band (UWB) antenna is proposed. To achieve ultra-wideband, a partial ground plane along with tapered feed has been included in the design. The proposed antenna has the capability of operating between 3.86GHz to 10.61GHz.

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# 1. Antennas

## 1.1 Introduction:

Communication has become the key to momentous changes in the organization of business and industries as they themselves adjust to the shift to an information economy. Information is indeed the lifeblood of modern economies and antennas provide mother earth a solution to a wireless communication system.An antenna is a transducer designed to transmit or receive electromagnetic waves. In other words, antennas convert electromagnetic waves into electrical currents and vice versa. They are used with waves in the radio part of the electromagnetic spectrum, that is, radio waves, and are a necessary part of all radio equipment. Antennas have many uses: communication, radar, telemetry navigation, etc. The figure shows the output from a coherent source (e.g. an oscillator) is directed out into free space using an antenna. The signal source is linked to the antenna by some kind of waveguide (microwave guide light fiber etc). The antenna acts as a sort of transformer. It takes the electromagnetic field pattern, moving along the guide and transforms it into some other pattern, which is radiated out into free space.

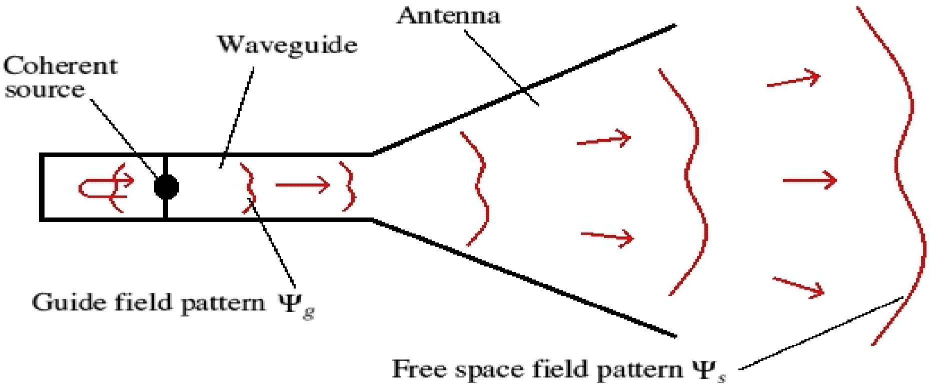


Fig 1.1: Schematic of an antenna system

Using this simple picture we can establish two basic properties of any antenna

- An antenna itself does not generate any power. So, unless the antenna is imperfect and dissipates some power the total power carried by the guide and free space fields must be the same. Practically, all antennas tend to be slightly resistive. So some power is normally lost, but for now, we can assume any loss is small enough to ignore.
- An antenna is a reciprocal device i.e., it behaves in the same way irrespective of the way we pass signal power through it. This reciprocal behavior is a useful feature of a coherent antenna. It means that in principle, the only difference between a “transmitting‟ and a “receiving‟ antenna is the direction we've chosen to pass signals through it.

## 1.2 Types of Antennas:

There are two fundamental types of antenna directional patterns, which with reference to a specific two-dimensional plane (usually horizontal [parallel to the ground][ or vertical perpendicular to the ground]) are either:

1.Omni-directional (radiates equally in all directions), such as a vertical rod (in the horizontal plane) or

2. Directional (radiates more in one direction than in the other)

In colloquial usage "omnidirectional” usually refers to all horizontal directions with reception above and below the antenna being reduced in favor of better reception near the horizon. A directional antenna usually refers to one focusing a narrow beam in a single specific direction such as a telescope or satellite dish, or, at least, focusing in a sector such as a 120° horizontal fan pattern in the case of a panel antenna at a cell site. The present antenna in the thesis i.e. Microstrip antenna is an omnidirectional antenna which radiates normal to the patch surface into the upper hemisphere (180° in elevation plane) and 360° in the azimuth plane.

### 1.2.1 Basic Models of Antennas:

There are many variations of antennas. Below are a few basic models.

- The **Isotropic radiator** is a purely theoretical antenna that radiates equally in all directions. It is considered to be a point in space with no dimensions and no mass. This antenna cannot physically exist but is useful as a theoretical model for comparison with all other antennas. Most antennas' gains are measured with reference to an isotropic radiator and are rated in dBi (decibels with respect to an isotropic radiator).
- The **Dipole antenna** is simply two wires pointed in opposite directions arranged either horizontally or vertically, with one end of each wire connected to the radio and the other end hanging free in space. Since this is the simplest practical antenna.
- The **Yagi-Uda** antenna is a directional variation of the dipole with parasitic elements added which are functionally similar to adding a reflector and lenses (directors) to focus a filament light bulb.
- The random **wire antenna** is simply a very long (at least one-quarter wavelength) wire with one end connected to the radio and the other in free space, arranged in any way most convenient for the space available. Folding will reduce effectiveness and make theoretical analysis extremely difficult.
- The **Parabolic antenna** consists of an active element at the focus of a parabolic reflector to reflect the waves into a plane wave. Like the horn, it is used for high gain, microwave applications, such as satellite dishes.
- The **Patch antenna** consists mainly of a square conductor mounted over a ground plane. Another example of a planar antenna is the tapered slot antenna (TSA), as the Vivaldi-antenna.

## 1.3 Basic Antenna Parameters:

### 1.3.1 Radiation Pattern:

An Antenna 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. In most cases, the radiation pattern is determined in the far-field region and is represented as a function of directional coordinates. The figure shows a symmetrical three-dimensional polar pattern with a number of radiation lobes.

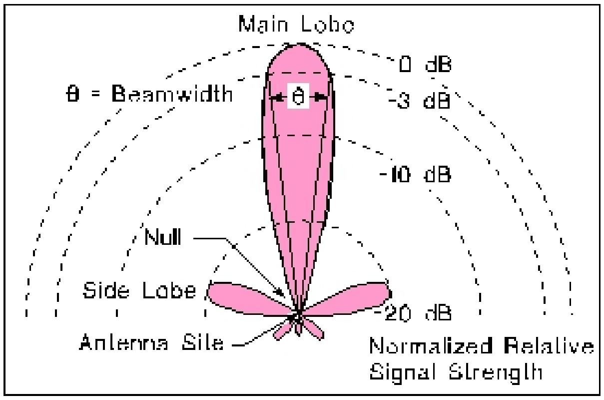


Fig 1.2: Radiation lobes of an antenna pattern

### 1.3.2 Beam Width:

The beam width of a pattern is defined as the angular separation between two identical points on the opposite side of the pattern maximum. One of the most widely used beam widths is the Half-Power Beam width (HPBW). Another important Beam width is the angular separation between the first nulls of the pattern, and it is referred to as the First Null Beam width (FNBW). Both HPBW and FNBW are shown in figure 1.3

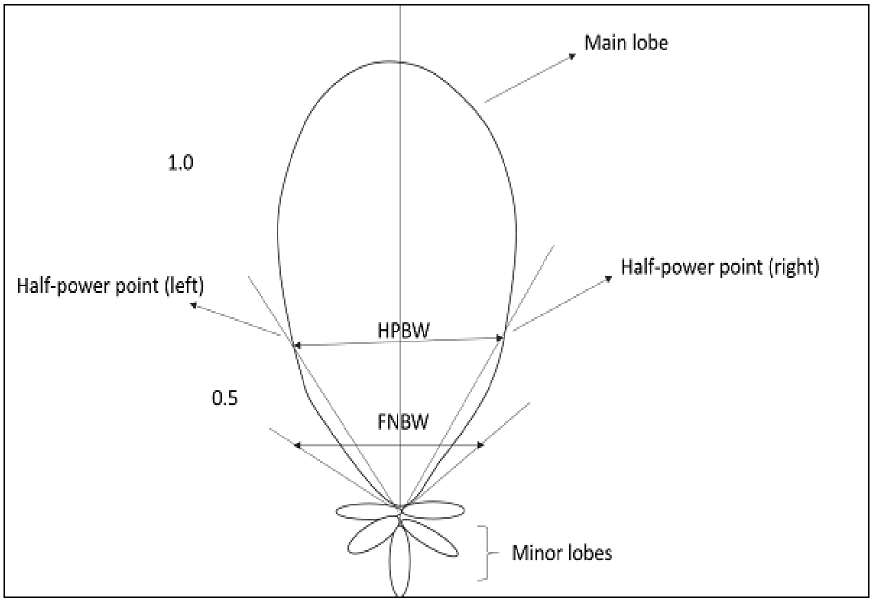


Fig 1.3: Beam width of an Antenna

### 1.3.3 Directivity:

The directivity of an antenna is “the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions". The average radiation intensity is equal to the total power radiated by the antenna divided by 4π.

$$\mathbf{D} = \frac{\mathbf{U}}{\mathbf{Uav}} = \frac{\mathbf{4\pi U}}{\mathbf{Prad}}$$

### 1.3.4 Gain:

The gain of the antenna is closely related to the directivity, it is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. A gain of an antenna is defined as “the ratio of intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically”. The radiation intensity corresponding to the isotropically radiated power is equal to the power accepted by the antenna divided by 4π.

$$\text{Gain} = \frac{4\pi(\text{Radiation Intensity})}{\text{Total input power}} = \frac{4\pi U(\theta,\varphi)}{P}$$

## 1.3.5 Effective Length:

The effective length represents the antenna in its transmitting and receiving modes and it is particularly useful in relating the open-circuit voltage Voc of receiving antennas. This relation can be expressed as

$$V_{oc} = E_i \times L_e$$

Where Voc=open-circuit voltage at antenna terminals,

Ei = incident electric field

Le = vector effective length

## 1.3.6 Antenna Equivalent Areas:

These equivalent areas are used to describe the power capturing characteristics of the antenna when a wave impinges on it. The different antenna equivalent areas are scattering area, loss area, capture area. The scattering area is defined as the equivalent area when multiplied by the incident power density is equal to the scattered or re radiated power. The loss area is defined as the equivalent area when multiplied by the incident power density leads to the power dissipated as heat through a load. The capture area is defined as the equivalent area when multiplied by the incident power density leads to the total captured, collected, or intercepted by the antenna. In general,

**Capture area = Effective area of scattering area+ loss area**

## 1.3.7 Antenna Efficiency:

The total efficiency E0 is used to take into account losses at the input terminals and within the structure of the antenna. Such losses may be due to reflections because of the mismatch between the transmission line and the antenna and IR losses due to the conductors and dielectric. In general overall efficiency can be written as

$$E0 = Er\ Ec\ Ed$$

Where E0 = Total efficiency
Er = Reflection efficiency
Ec = Conduction efficiency
Ed = Dielectric efficiency

### 1.3.8 Input impedance:

The input impedance of an antenna is impedance presented by an antenna at its terminals. The antenna impedance $Z_A$ can be expressed as,

$$Z_A = R_A + jX_A\ \Omega$$

Where $R_A$ is the antenna resistance in ohms and XA is the antenna reactance in Ohms. The radiation Resistance is expressed as

$$R_A = R_r + R_L\ \Omega$$

Where $R_r$ is the radiation resistance and $R_L$ is the loss resistance. The radiation resistance is associated with the radiation of real power. For a lossless antenna, the input resistance reduces the radiation resistance. The input impedance is also the ratio of the voltage to current at its terminal or the ratio of the appropriate electric and magnetic fields at a point.

### 1.3.9 Bandwidth:

The bandwidth of an antenna is that frequency range over which it will perform within certain specified limits. These limits are with respect to impedance match, gain, and/or radiation pattern characteristics.

Typical specification limits are:

- An impedance mismatch of less than 2:1 relative to some standard impedance such as 50 ohms

- A loss in gain or efficiency of no more than 3 dB.
- A directivity pattern whose main beam is 13 dB greater than any of the side lobes, and a back lobe at least 15 dB below the main beam
- Bandwidth is measured by changing the frequency of a constant strength test n above and below center frequency and measuring power output. The high and low frequencies, where power is one-half (-3 dB) of what it was at the center, define the bandwidth. It is expressed as frequency (high minus low) or in percentage (high-low/centre*100%).Figure1.4 shows the typical bandwidth plot of the microstrip antenna.

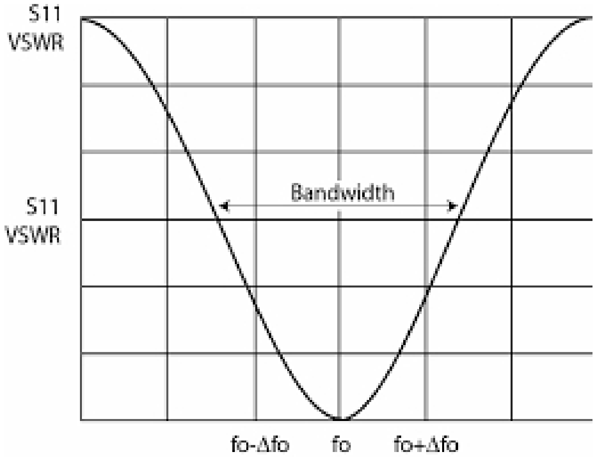


Fig 1.4: Bandwidth of the antenna

### 1.3.10 Reflection coefficient and Return loss:

**Reflection Coefficient** shows what fraction of an incident signal is reflected when a source drives a load. A **reflection coefficient** magnitude of zero is a perfect match; a value of one is a perfect reflection. The symbol for the reflection coefficient is uppercase Greek Letter gamma (ɼ). Note that the reflection coefficient is a vector, so it includes an angle. Unlike VSWR, the reflection coefficient can distinguish between short and open circuits. A short circuit has a value of -1(1 at an angle of 180 degrees), while an open circuit is one at an angle of 0 degrees. Quite often we refer to only the magnitude of the reflection coefficient.

**Return Loss** shows the level of the reflected signal with respect to the incident signal in dB. The negative sign is dropped from the return loss value, so a large value for return loss indicates a small reflected signal. The **return loss** of a load is merely the magnitude of the reflection coefficient expressed in decibels.

The correct equation for return loss is:

$$\textbf{Return Loss} = \mathbf{-20Log\ (\Gamma)}$$

Thus in its correct form, return loss will usually be a positive number. If it's not, you can usually blame measurement error. The exception to the rule is something with negative resistance, which implies that it is an active device (external DC power is converted to RF) and it is potentially unstable it could oscillate).

## 1.3.11 Voltage Standing Wave Ratio (VSWR):

VSWR describes how much energy is reflected from the antenna because of impedance mismatching. A perfectly impedance matched antenna would have VSWR equal to one. Return loss (RL) is often used as it illustrates the gain reduction that would be introduced due to the mismatch of the antenna. VSWR is very important for wireless communications because the received signals from the satellites are usually very weak (on the order of -160 dB) and reflections are undesired on the transmission line connecting the antenna and the receiver. VSWR less than 2:1 (equivalent to a return loss of -9.5dB) is considered to be acceptable for most wireless applications because the time delay of any reflections is typically small, thus providing small amounts of error within the receiver. A lower VSWR may be required for particularly high-performance applications and unique installations

$$\mathbf{VSWR = (1+\Gamma) / (1-\Gamma)}$$

### 1.3.12 Polarization:

A radiated wave‟s polarization is determined by the direction of the lines of force making up the electric field. If the lines of electric force are at right angles to the Earth's surface, the wave is vertically polarized. If the lines of electric force are parallel to the Earth's surface, the wave is horizontally polarized as shown in Figure 1.5. When a single-wire antenna extracts (receives) energy from a passing radio wave, maximum pickup results if the antenna is oriented in the same direction as the electric field component.

A vertical antenna receives vertically polarized waves, and a horizontal antenna receives horizontally polarized waves. If the field rotates as the waves travel through space, both horizontal and vertical components of the field exist, and the wave is elliptically polarized. Generally, the antenna radiates an elliptical polarization, which is defined by three parameters: axial ratio, tilt angle, and sense of rotation. When the axial ratio is infinite or zero, the polarization becomes linear with the tilt agile defining the orientation. The quality of linear polarization is usually indicated by the level of the cross-polarization. For the unity axial ratio, a perfect circular polarization results and the tilt angle is not applicable.

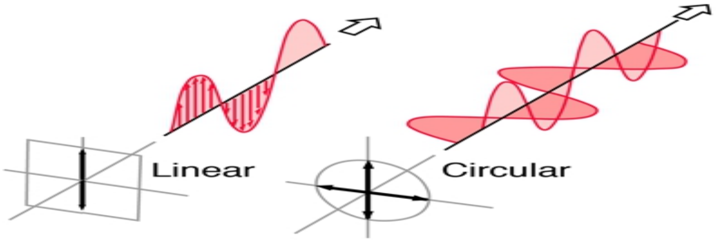


Fig 1.5: Linear and circular polarization of an antenna

In general, the axial ratio is used to specify the quality of circularly polarized waves as shown. Antennas produce circularly polarized waves when two orthogonal field components with equal amplitude but in phase quadrature are radiated.

### 1.3.13 Axial ratio:

The Axial Ratio is the ratio of orthogonal components of an E-field. A circularly polarized field is made up of two orthogonal E-field components of equal amplitudes and 90 degrees out of phase). Because the components are equal magnitude, the Axial Ratio is 1 (or 0 dB).In order to check the polarization of the designed antenna, the axial ratio (AR) was calculated and analyzed. The axial ratio, as defined, is the ratio of the major axis to the minor axis of the tilted ellipse formed by the electric field of elliptically polarized waves.

$$\text{Axial ratio (AR)} = \text{major axis}/\ \text{minor axis}\quad 1 \leq AR \leq \infty$$

## 1.4 Equivalent Diagram of an antenna:

A transmission-line Thevenin equivalent of the antenna system is shown in figure Source is represented by an ideal generator, the transmission line is represented by a line with characteristics impedance Zs, and the antenna is represented by a load $Z_L$ where,

$$Z_L = R_L + j\,X_L$$

The load resistance RL is used to represent the conduction and dielectric losses associated with antenna structure while $R_r$ referred to as the radiation resistance, is used to represent radiation by the antenna. The reactance XL is used to represent the imaginary part of the impedance associated with radiation by the antenna. Taking into account the internal impedance of the source and neglecting line and reflection(mismatch) losses, maximum power is delivered to the antenna under conjugate matching.

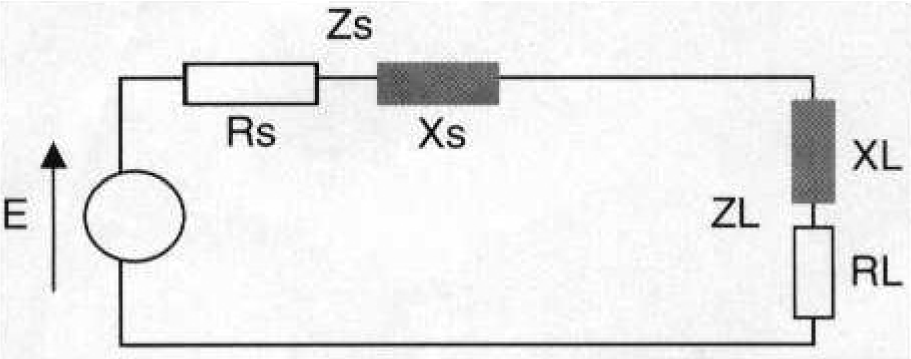


Fig 1.6: Equivalent diagram of an antenna

# 2. Microstrip Patch Antennas

## 2.1 Introduction

Microstrip antennas are attractive due to their lightweight, conformability, and low cost. These antennas can be integrated with printed strip-line feed networks and active devices. This is a relatively new area of antenna engineering. The radiation properties of microstrip structures have been known since the mid-1950s.

The application of this type of antennas started in the early 1970s when conformal antennas were required for missiles Rectangular and circular microstrip resonant patches have been used extensively in a variety of array configurations. A major contributing factor for recent advances of microstrip antennas is the current revolution in electronic circuit miniaturization brought about by developments in large scale integration. As conventional antennas are often bulky and costly part of an electronic system, microstrip antennas based on photolithographic technology are seen as an engineering breakthrough.

In its most fundamental form, a Microstrip Patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

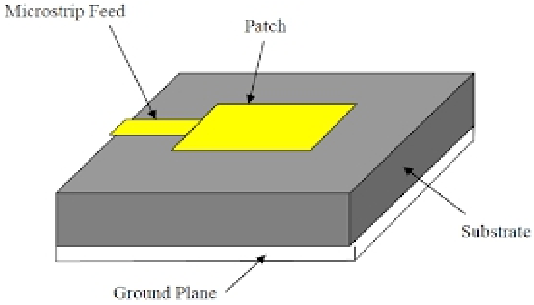


Fig.2.1: Basic Structure of a Microstrip Patch Antenna

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape. For a rectangular patch, the length L of the patch is usually $0.3333\ \lambda_0 < L < 0.5\ \lambda_0$ where $\lambda_0$ is the free-space wavelength. The patch is selected to be very thin such that $t \ll \lambda_0$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\ \lambda_0 \leq h \leq 0.05\ \lambda_0$ . The dielectric constant of the substrate ( $\varepsilon_r$) is typically in the range of $2.2 \leq \varepsilon_r \leq 12$.

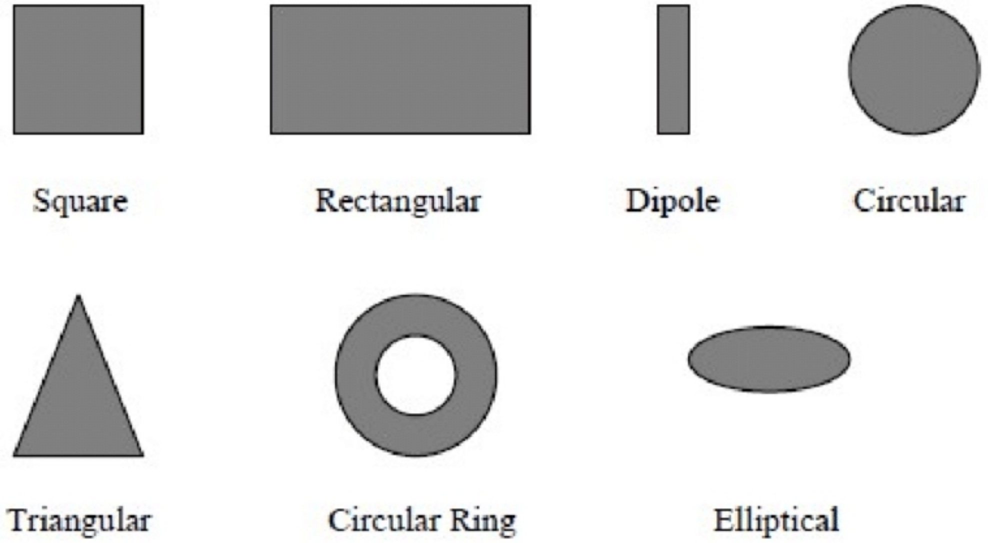


Fig.2.2: Common shapes of microstrip patch elements

Depending on the shapes of the patch, patch antennas are divided into rectangular patch antenna, triangular patch antenna, circular patch antenna,etc. Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency. Larger bandwidth and better radiation. However, such a configuration leads to larger antenna size. In order to design a compact Microstrip patch antenna, substrates with higher dielectric constants must be used which are less efficient and result in narrow between the antenna dimensions and antenna performance bandwidth. Hence a trade-off must be realized between the antennas dimensions and antennas performance.

## 2.2 Microstrip structures:

A microstrip structure is made with a thin sheet of low-loss insulating material called the dielectric substrate. It is completely covered with metal on the inside, called the ground plane, and partly metalized on the other side, where the circuit or antenna shapes are printed. Components can be included in the circuit either by it planting lipid components (resistors, inductors, capacitors, semiconductors, and ferrite devices) or by realizing them directly within the circuit. Each part of the microstrip structure will be explained in detail as follows:

### 2.2.1 Dielectric Substrate:

The dielectric substrate is the mechanical backbone of the microstrip circuit It provides stable support for the conductor strips and patches that make up conducting lines, resonators, and antennas. It ensures that the components that are implanted are properly located and firmly held in place, just as in printed circuits for electronics at lower frequencies. The substrate also fulfills an electric function by concentrating the electromagnetic fields and preventing unwanted radiation in circuits. The dielectric is an integral part of the connecting transmission lines and deposited components its permittivity and thickness determine the electrical characteristics of the circuit or of the antenna.

### 2.2.2 Conductor Layers:

Nowadays, many commercial suppliers provide a wide range of microstrip substrates already metallized on both faces. The conductor on the upper face is chemically etched to realize the circuit pattern by a photography technique. A mask of the circuit of the antenna is drawn, generally at a convenient scale, and then reduced and placed in close contact with a photo resistive layer, which has previously deposited on top of the metallized substrate.

The lower metal part is the ground plane. The ground plane, besides acting as mechanical support, provides for the integration of several components and serves also as a heat sink and de-bias return for active devices. The resulting sandwich is then exposed to ultraviolet rays, which reach the photosensitive layer where it is not covered by the mask. The exposed parts are removed by the photographic development, and the metal cover is etched away from the exposed area. This process is called the subtractive process. Alternatively, one may wish to use a bare dielectric substrate as a starting material and deposit metal either by evaporation or by sputtering through the holes in the mask. This is called the additive thin film process. In the thick-film process, a metallic paste is squeezed through the holes in a mask deposited over a silkscreen. The latter approach, however, is less accurate and it seldom used at very high frequencies.

## 2.3 Waves on Microstrip:

The mechanisms of transmission and radiation in a microstrip can be understood by considering a point current source (Hertz dipole) located on top of the grounded dielectric substrate This source radiates electromagnetic waves. Depending on the direction toward which waves are transmitted, they fall within three distinct categories, each of which exhibits different behaviors.

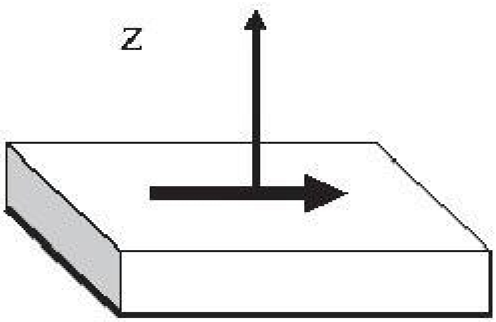


Fig.2.3: Hertz dipole on a microstrip substrate

## 2.3.1 Surface Waves:

The waves transmitted slightly downward, having elevation angles between $\pi/2$ and $\pi$ arcs in $(1/\sqrt{\varepsilon_r})$, meet the ground plane, which reflects the, and then meet the dielectric to air boundary, which also reflects them (total reflection condition). The magnitude of the field amplitudes builds up for some particular incidence angles that lead to the excitation of a discrete set of surface wave modes, which are similar to the modes in metallic waveguide.

The fields remain mostly trapped within the dielectric, decaying exponentially above the interface. The vector alpha, pointing upward, indicates the direction of the largest attenuation. The wave propagates horizontally along , with little absorption in a good quality dielectric. With two directions of and orthogonal to each other, the wave is a non-uniform plane wave. Surface waves spread out in cylindrical fashion around the excitation point, with field amplitudes decreasing with distance (r), says 1/r, more slowly than space waves. The same guiding mechanism provides propagation within optical fibers.

Surface waves take up some part of the signal's energy, which does not reach the intended user. The signal's amplitude is thus reduced, contributing to n apparent attenuation or a decrease in antenna efficiency. Additionally, surface waves also introduce spurious coupling between different circuits of antenna elements. This effect severely degrades the performance of microstrip filters because the parasitic interaction reduces the isolation in the stop bands.

In large periodic phased arrays, the effect of surface wave coupling becomes particularly obnoxious, and the array can neither transmit nor receive when it is pointed at some particular directions (blind spots). This is due to a resonance phenomenon when the surface waves excite in synchronism the floquet modes of the periodic structure Surface waves reaching the outer boundaries of an open microstrip structure are reflected and refracted by the edges. The diffracted waves provide an additional contribution to radiation, degrading the antenna pattern by raising the side lobe and the cross-polarization levels. Surface wave effects are mostly negative, for circuits and for antennas, so their excitation should be suppressed if possible.

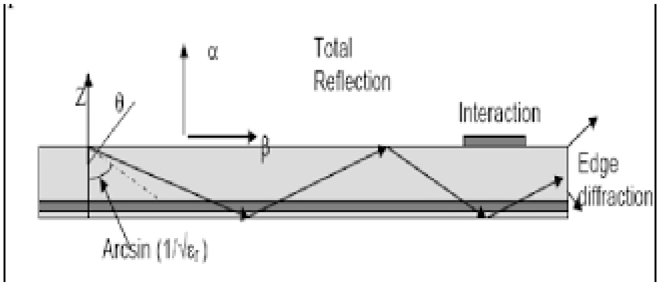


Fig 2.4: Surface waves

## 2.3.2 Leaky Waves:

Waves directed more sharply downward, with π angles between π arcs in $1/\sqrt{\varepsilon_r}$ and π, are also reflected by the ground plane but only partially by the dielectric-to-air boundary. They progressively leak from the substrate into the air, hence their name leaky waves, and eventually contribute to radiation. The leaky waves are also non uniform plane waves for which the attenuation direction points downward, which may appear to be rather odd; the amplitude of the waves increases as one moves away from the dielectric surface.

This apparent paradox is the field amplitude increase in the move away from the substrate became the wave radiates from a poi where the signal amplitude is larger Since the structure is finite this apparent divergent behavior can only exist locally and the wave vanishes abruptly as one crosses the trajectory of the first ray.

In more complex structures made with several layers of different dielectrics, leaky waves can be used to increase the apparent antenna size and provide larger gains. This occurs for favorable stacking arrangements and at a particular frequency. Conversely, leaky waves are not excited in some other multilayer structures.

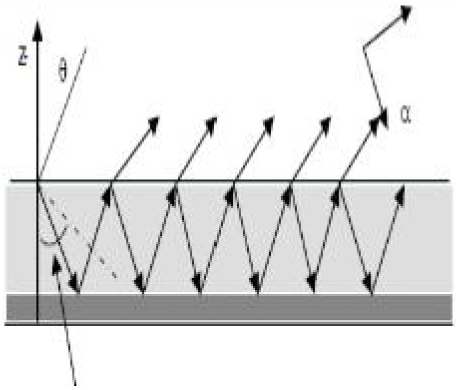


Fig 2.5: Leaky waves

### 2.3.3 Guided Waves:

When realizing printed circuits, one locally adds a metal layer on top of the substrate which modifies the geometry, introducing an additional reflecting boundary. Waves directed into the dielectric located under the upper conductor bounce back and forth on the metal boundaries, which form a parallel plate waveguide. The waves in the metallic guide can only exist for some Particular values of the angle of incidence, forming a discrete set of waveguide modes. The guided waves provide the normal operation of all transmission lines and circuits, in which the electromagnetic fields are mostly concentrated in the volume below the upper conductor. On the other hand, this build-up of electromagnetic energy is not favorable for patch antennas, which behave like tests with a limited frequency bandwidth.

## 2.4 Microstrip Antenna Types:

### 2.4.1 Microstrip Dipole:

The small size of the dipole antennas makes them attractive for many applications but also results in the very narrow frequency bandwidth. No transverse current flows on a narrow dipole, so the cross-polarization level is inherently low.

A microstrip dipole is usually fed by a balanced feed, for instance, a parallel two-wire line printed on the substrate or two wires connected through the substrate. Transitions or baluns must then be incorporated to connect the feed to a microstrip line or to a coaxial line, which is both inherently unbalanced transmission lines. Alternatively, dipoles may also be fed by electromagnetic coupling with embedded feed lines.

## 2.4.2 Microstrip Patch:

Printed patch antennas use radiating elements of a wide variety of shapes. Square, rectangle, circle, ring, triangle more complex geometrical figures, and a combination of simpler shapes are also used for the applications. The selection of a particular shape depends on the parameters one wishes to optimize bandwidth, side lobes cross-polarization, and antenna size.

Microstrip patches present a somewhat broader relative bandwidth than dipoles, of the order of a few percents. In contrast to thin dipoles, patches may excite some surface current flowing across the transverse direction, which then radiates an unwanted cross-polarized component. Its amplitude is critically dependent on the kind of feed and its location with respect to the axes of the patch.

### 2.4.2.1 Rectangular Patches

The geometry-shape most commonly used to realize microstrip patch antennas are the rectangle. A rectangular patch can be considered to be an open-ended section of transmission line of length L and width W. The fringing fields at the two ends are accounted for by adding equivalent L at both ends.

$$Fm = \frac{mco}{2(L+\Delta L)}$$

With the integer m=1,2,3($\neq 0$ ) and relative permittivity, $_e$ is given by the equation where co is free space speed of light, and $_e$ is the effective permittivity of the substrate. This expression is for resonant modes in which surface current is mostly longitudinal,more complex resonance patterns are obtained for higher-order modes on wide lines.

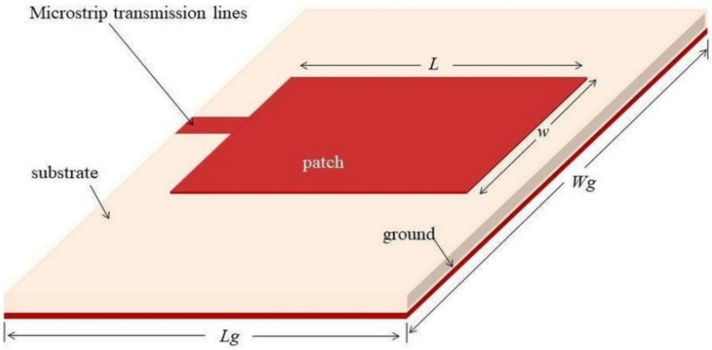


Fig 2.6: Rectangular Patch

The lines of surface current correspond, respectively, to the $TM_{100}$ and the $TM_{010}$ the $TM_{110}$ for an equivalent sure shaped cavity having perfect magnetic conductor (PMC) sidewalls.

### 2.4.2.2 Circular Patches:

Circular patches were reported to lose energy by radiation and thus provide large-quality factors than rectangular pulses. The resonant frequency is determined by assuming that a perfect wall (PMC) extends under the edges of the patch Fringing fields are taken into account by defining effective resonator radius $a_e$ which is slightly larger than the physical radius (a).

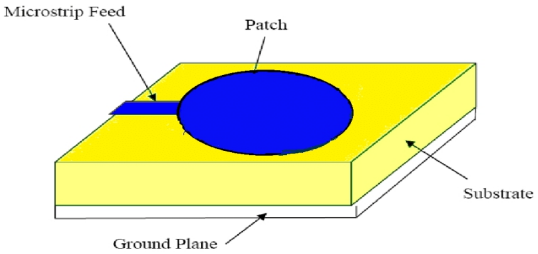


Fig.2.7: Circular Patch

## 2.5 Feeding 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 isdone to transfer power between the microstrip 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).

### 2.5.1 Microstrip Line Feed:

In this type of feed technique, a conducting strip is connected directly to the edge of the Microstrip patch. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

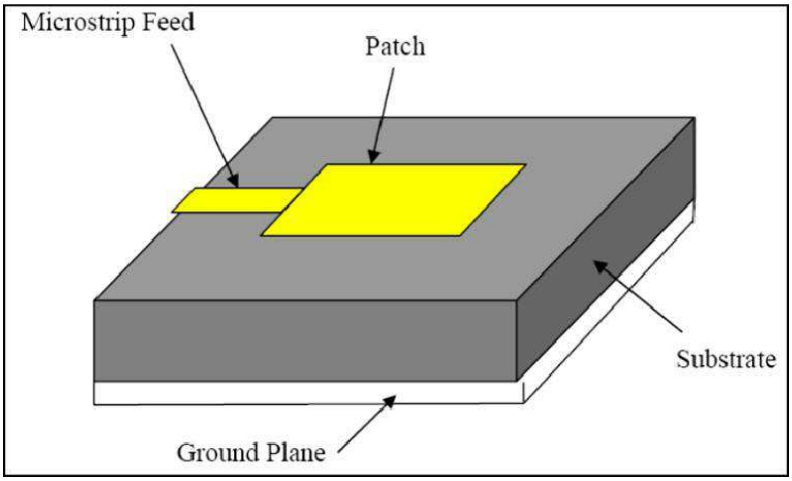


Fig 2.8 Micro strip line feed

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme since it provides ease of fabrication and simplicity in modeling as well as impedance matching. However as the thickness of the dielectric substrate being used, it increases surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna. The feed radiation also leads to undesired cross polarized radiation.

### 2.5.2 Coaxial Feed:

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure-2.9, 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.

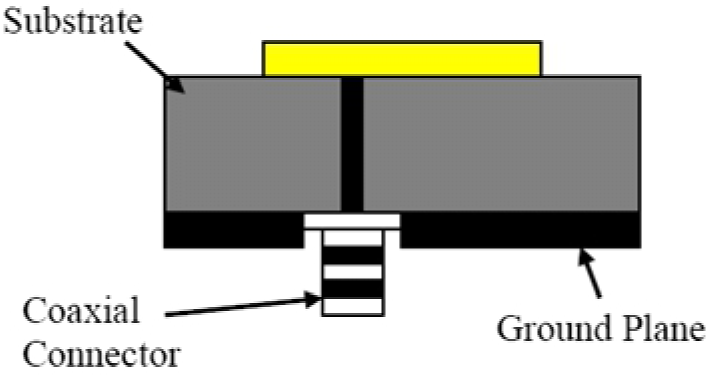


Fig 2.9: Probe fed Rectangular Microstrip Patch Antenna

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 planer for thick substrates ($r > 0.020\lambda_0$ ). Also, for thicker substrates the increased probe length makes the input impedance more inductive, leading to matching problems. It is seen above that form thick dielectric substrate, which provides broad bandwidth; the microstrip line feed and the coaxial feed suffer from numerous disadvantages.

### 2.5.3 Aperture Coupled Feed:

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane. The coupling aperture is usually cantered under the patch, leading to lower cross-polarization due to the symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size, and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized.

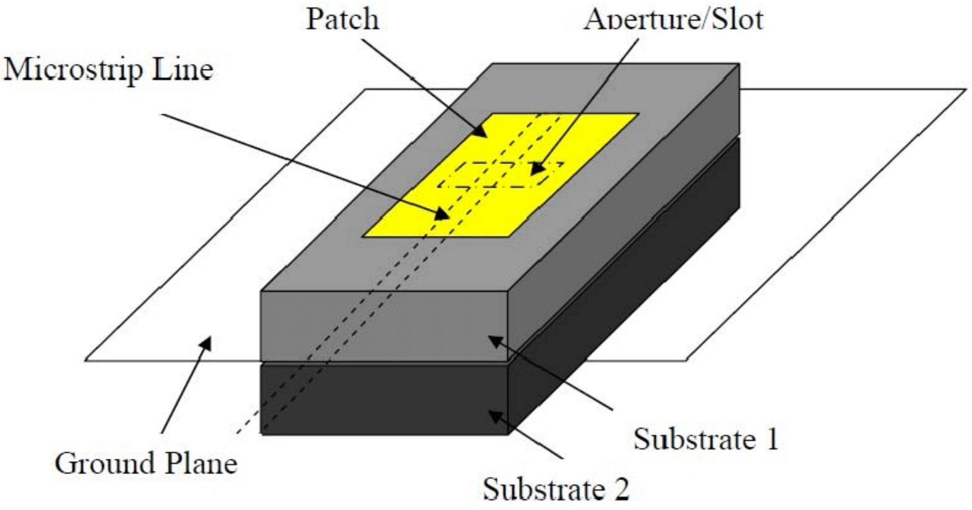


Fig.2.10: Aperture-coupled feed

The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers which also increases the antenna thickness. This feeding scheme also provides a narrow bandwidth.

### 2.5.4 Proximity Coupled Feed:

This type of feed technique is also called as the electromagnetic coupling scheme. 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 the 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.

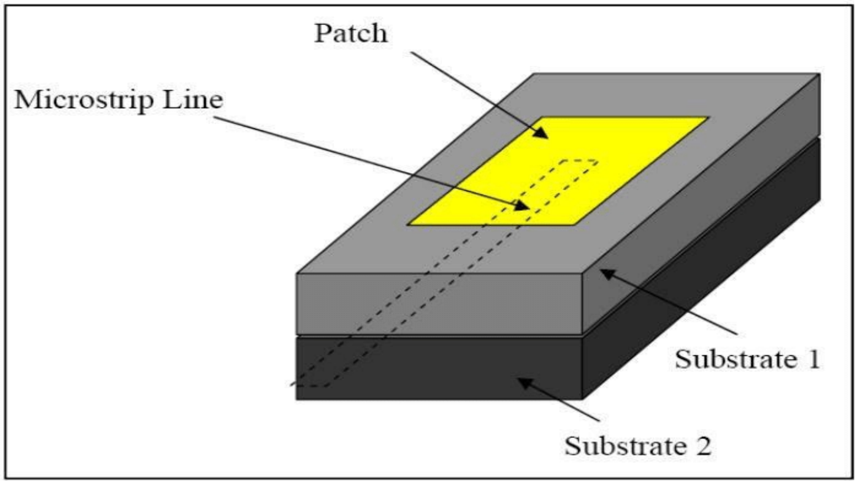


Fig.2.11 Proximity-coupled Feed

## 2.6 Methods of Analysis:

There are many methods of analysis for microstrip antennas. The most popular models are the transmission-line, cavity, and full-wave (which include primarily integral equations/Moment Method). 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 Compared to the 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, although it has been used successfully.

The full-wave models are very accurate, very versatile, and can treat single elements, finite and infinite arrays, stacked elements, arbitrarily shaped elements, and coupling. However, they are the most complex models and usually give less physical insight. The rectangular patch is by far the most widely used configuration. It is very easy to analyze using both the transmission-line and cavity models, which are most accurate for thin substrates. We begin with the transmission-line model because it is easier to illustrate.

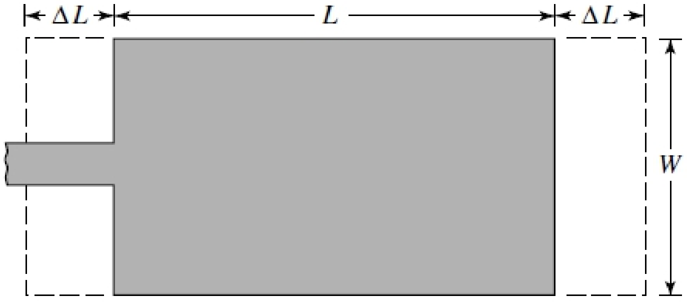
### 2.6.1 Transmission-Line Model:

The transmission-line model is the easiest of all but it yields the least accurate results and it lacks versatility. Basically the transmission-line model represents the microstrip antenna by two slots, separated by a low-impedance transmission line of length L.

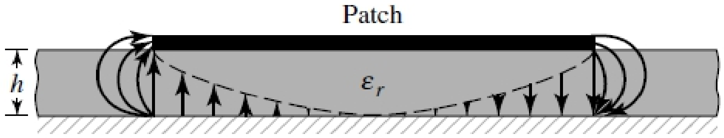
#### 2.6.1.1 Fringing effects:

The dimensions of the patch are finite along the length and width: the fields at the edges of the patch undergo fringing. The amount of fringing is a function of the dimensions of the patch and the height of the substrate. For the principal E-plane (XY- plane) fringing is a function of the ratio of the length of the patch L to the height h of the substrate (L/h) and the dielectric constant antennas of the substrate. Since for microstrip antennas L/h>>1, fringing is reduced. The same applies for the width.

The figure 2.12 shows the non-homogeneous line of two dielectrics, typically the substrate and air. Most of the electric field lines reside in the substrate and parts of some lines exist in the air. As W/h>>1 and $\varepsilon_r >> 1$ the electric field lines concentrate mostly in the substrate. Fringing, in this case, makes the microstrip line look wider electrically compared to its physical dimensions. Since some of the waves travel in the substrate and some in air, an effective dielectric constant $\varepsilon_{reff}$ is introduced to account for fringing and the wave propagation in the line is shown in Figure 2.12. The effective dielectric constant has values in the range of $1 < \varepsilon_{reff} < \varepsilon_r$ The effective dielectric constant is also a function of frequency, as the frequency of operation increases, most of the electric field lines concentrate in the substrate.



(a) Top view

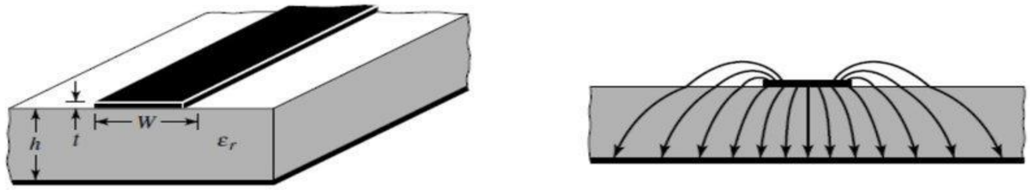


(b) Side view

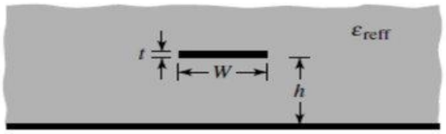
Fig 2.12: Physical and effective lengths of rectangular microstrip patch

### 2.6.1.2 Effective Length, Resonant Frequency, and Effective Width:

Because of the fringing effects, electrically the patch of the microstrip antenna looks greater than its physical dimensions. The dimensions of the patch along its length have been extended on each end by a distance ΔL, which is a function of the effective dielectric constant $\varepsilon_{reff}$ and the width-to-height ratio (W/h) is given. Since the length of the patch has been extended by ΔL on each side, the effective length of the patch is now $L_{eff} = L+2\ \Delta L$



(a) Microstrip line (b) Electric field lines



(c) Effective dielectric constant

Fig 2.13 Micro strip line and its electric field lines and effective dielectric constant geometry.

## 2.6.2 Cavity Model:

Although the transmission line model discussed in the previous section is easy to use, it has some inherent disadvantages: Specifically, it is useful for patches of rectangular design and it ignores field variations along the radiating edges. These disadvantages can be overcome by using the cavity model. A brief overview of this model is given below. In this model, the interior region of the dielectric substrate is modeled as a cavity bounded by electric walls on the top and bottom. The basis for this assumption is the following observations for thin substrates

- Since the substrate is thin the fields in the interior region do not vary much in the z-direction, it normal to the patch.
- The electric field is z directed only, and the magnetic field has only the transverse components H, and H, in the region bounded by the patch metallization and the ground plane. This observation provides for the electric walls at the top and the bottom.

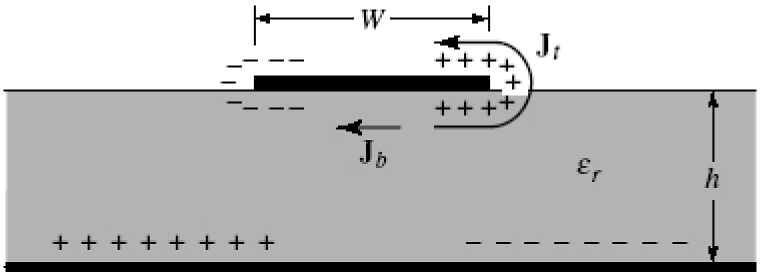


Fig 2.14: Charge distribution and current density creation on the microstrip patch

When the microstrip patch is provided power, a charge distribution is seen on the upper and lower surfaces of the patch and at the bottom of the ground plane as shown in figure-2.14 this charge distribution controlled by two mechanisms-an attractive mechanisms and a repulsive mechanism.

The attractive mechanism is between the opposite charges on the bottom side of the patch and the ground plane, which helps in keeping the charge concentration intact at the bottom surface of the patch, which causes pushing of some charges from the bottom, to the top of the patch. the bottom of the patch. The propulsive mechanism is between the like charges. As a result of this charge movement, currents flow at the top and bottom surface of the patch

The cavity model assumes that the height to width ratio(i.e. the height of the substrate and width of the patch) is very small and as a result of this the attractive mechanism dominates and causes most of the charge concentration and the current to be below of the patch surface. Much less current would flow on the top surface of the ratio further decreases, the current on the top surface will be almost equal to zero, which would not allow the creation of any tangential magnetic field components to the patch edges. Hence, four sidewalls could be modeled as perfectly magnetic conducting surfaces.

This implies that the magnetic fields and the electric field distribution beneath the patch would not be disturbed. However, in practice, a finite width to height ratio would be there and this would not make the tangential magnetic fields to be completely zero, but they being very small, the side walls could be approximately to be perfectly magnetic conducting.

Since the wall of the cavity, as well as the material within it, is lossless, the cavity would not radiate and its input impedance would be purely reactive. Hence, in order to account for radiation and a loss mechanism, one must introduce a radiation resistance $R_R$ and a loss resistance $R_L$.

## 2.7 Circularly Polarized Microstrip Patch Antennas:

### 2.7.1 Types of Circularly Polarized microstrip Patch antenna:

A microstrip patch is one of the most widely used radiators for circular polarization. Figure2.15 shows some patches, including square, circular, equilateral triangular, ring, and elliptical shapes which are capable of circular polarization operation. However, square and circular patches are widely utilized in practice. A single patch antenna can be made to radiate circular polarization if two orthogonal patch modes are simultaneously excited with equal amplitude and 90 out of phase with sign determining the sense of rotation. Two types of feeding schemes can accomplish in the task. The first type is dual-orthogonal food, which employs an external power divider network. The other is a single point for which an external power divider is not required

#### 2.7.1.1 Dual-Orthogonal Fed circularly Polarized microstrip Patch antenna:

The patch is usually square or circular. The dual-orthogonal feeds excite two orthogonal modes with equal amplitude but in-Phase quadrature. Several power divider circuits that have been successfully employed for CP generation include the quadrature hybrid, the ring hybrid, the Wilkinson power divider, and the Function power splitter. The quadrature hybrid splits the input into two outputs with an equal magnitude but 90 out of phase. However, breed a quarter wavelength line in one of the output arms to produce a 90 phase shift at the two feeds.

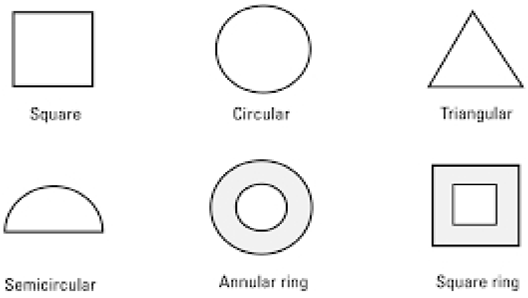
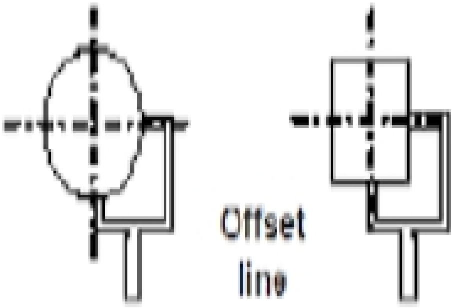


Fig 2.15: Various types of circularly polarized microstrip patch antennas



**(a)** **(b)**

Fig 2.16: Typical configurations of dual-fed circularly Polarized microstrip Antennas: a) circular patch (b) square patch

### 2.7.1.2 Singly Fed Circularly Polarized microstrip Patch antenna:

Typical configurations for a singly fed CP microstrip antenna are shown in the sheet. A single point feed patch capable of producing CP radiation is very desirable in situations where it is difficult to accommodate dual-orthogonal feeds with a power divider network. Because a patch with single-point feed generally radiates linear polarization, in order to radiate CP, it is necessary for two orthogonal patch modes with equal amplitude an in-phase quadrature to be induced. Perturbation configurations for generating CO operate on the principle o detuning Degenerate modes of the syndical patch by perturbation some shown in figure 2.17. The fields of a singly fed patch can be resolved orthogonal degenerate modes and. Proper perturbation sets will detune frequency response of mode 2 such that at the opening frequency of the axial ratio rapidly degrades while the input match remains acceptable.

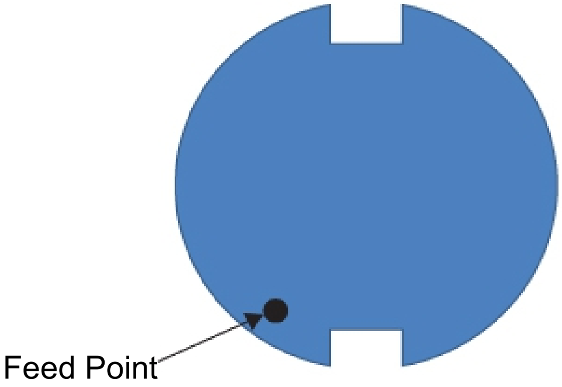


Fig 2.17: Typical configurations of singly fed circularly polarized microstrip antenna

Circular polarization can also be obtained from a single-point-fed square of the circular patch on normally biased ferrite substrate, as shown in figure 2.17. Polar demonstrated that a singly fed patch radiates both left hand circularly polarized(LHCP) and right and circularly polarized(RHCP) at the same level and polarity of bias magnetic field however LHCP and RHCP have different resonant frequencies. At the same operating frequency, the polarization can be reversed by reversing the polarity of the bias field. The axial ratio bandwidth is found to be larger than the impedance bandwidth. The radiation efficiency is 70%.

Dual circular polarization has also been achieved using a singly fed triangular or Pentagonal microstrip antenna. A triangular patch radiates CP at dual frequencies, f1 and f2, with the separation ratio depending on the aspect ratio b/a. RHCP can be changed to

LHCP at each frequency by moving the feed location into 2 from 4 to 3. The aspect ratio b/a is generally very close to unity, hence, a triangular patch is almost equilateral. A pentagonal patch in figure 2.17, with the aspect ratio c/an as a design parameter, also behaves in a similar manner, It radiates RHC when the feed point.

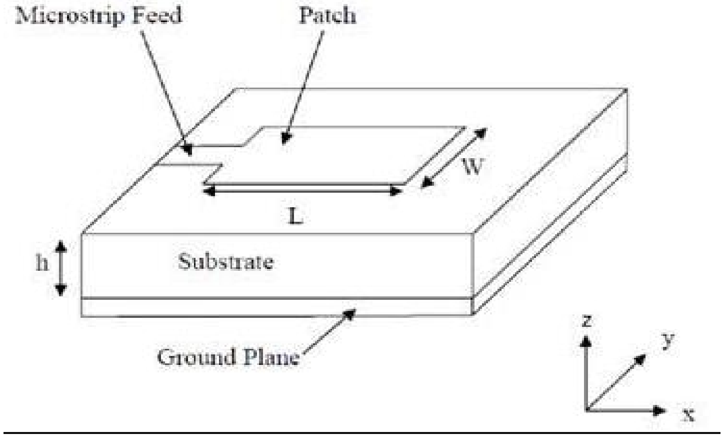


Fig 2.18: Geometry of a rectangle patch antenna on a normally biased substrate

## 2.8 Advantages and Disadvantages:

Microstrip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Therefore they are extremely compatible with embedded antennas in handheld wireless devices such as cellular phones, pagers, etc. The telemetry and communication antennas on missiles need to be thin and conformal and are often in the form of Microstrip patch antennas. Another area where they have been used successfully is in Satellite communication.

- Lightweight and low volume
- Low profile planar configuration which can be easily made conformal to host surface
- Low Fabrication cost, hence can be manufactured in large quantities
- Supports both, linear as well as circular polarization.
- It can be easily integrated with microwave integrated circuits (MIC).
- Capable of dual and triple frequency operations

- Mechanically robust when mounted on rigid surfaces
- Microstrip patch antennas suffer from more drawbacks as compared to conventional antennas

Some of their major disadvantages are given below:

- Narrow bandwidth
- Low efficiency
- Low Gain
- Extraneous radiation from foods and junctions
- Poor end-fire radiator except for tapered slot antennas
- Low power handling capacity
- Surface wave excitation

Microstrip patch antennas have a very high antenna quality factor (Q). It represents the losses associated with the antenna where a large O leads to narrow bandwidth and low efficiency. Q can be reduced by increasing the thickness of the dielectric substrate. But as the thickness increases, an increasing fraction of the total power delivered by the source goes into a surface wave. This surface wave contribution can be counted as an unwanted power loss since it is ultimately scattered at the dielectric bends and causes degradation of the antenna characteristics. Other problems such as lower gain and lower power handling capacity can be overcome by using an array configuration for the elements.

## 2.9 Applications:

Microstrip antenna has found applications in telemetry, satellite communication, and various military radar systems.Opening in the 1 to 10 GHz frequency range. It is mainly due to advantages like low profile and case or at integrating the microstrip antenna with the solid-state receiving or transmitting module opens up the possibility of building large antenna array system with each element being an active individually controlled element application of microstrip antenna is tabulated below

| | |
|---|---|
| Aircraft | Radar communications,<br>Navigation landing system |
| Missiles | Radar, Telemetry |
| Satellites | Communication direct broadcast TV |
| Ships | Radar communication  navigation |

Table 2.1: Various applications of Microstrip antenna

## 2.9.1 Mobile and satellite communication application:

Mobile communication requires small low-cost low profile antennas. Microstrip patch antenna meets all Requirements and various types of microstrip antennas have been designed for use in mobile communication systems. In the case of satellite communication, circularly polarized radiation patterns are required and can be realized using either a square or circular patch with one or two feed points.

## 2.9.2 Global Positioning System applications:

Nowadays microstrip patch antennas with a substrate having high permittivity sintered material are used for the global positioning system. This antenna sure circularly polarized very compact and quite expensive due to its positioning. It is expected that millions of GPS receivers will be used by the general population for land vehicle aircraft and maritime vessels to find there position accurately.

### 2.9.3 Radio Frequency Identification (RFID):

RFID in different areas like mobile communication, logistics, manufacturing, transportation, and health care RFID system songs frequencies between 30 Hz and 5.8 GHz depending on its applications RFID system is a tag or transponder and a transceiver.

### 2.9.4 Worldwide Interoperability for Microwave Access (WiMax):

The IEEE 802.16 Standard is known as WiMax. It can reach up to a 30-mile radius theoretically and data rate 70 Mbps. MPA generates three resonant modes at 2.7, 3.3 and 5.3 GHz, and can, therefore, be used in WiMax compliant communication equipment.

**Radar Application:** Radar gun is used for detecting moving targets such as people and vehicles. It demands a low profile, lightweight antenna subsystem, the microstrip antennas are an ideal choice. The fabrication technology based on photolithography enables the bulk production of microstrip antenna with a repeatable performance at a lower cost in a lesser time frame as compared to the conventional antennas.

**Rectenna Application:** Rectenna is a rectifying antenna, a special type of antenna that is used to directly convert microwave energy into DC power. Rectenna is a combination of four subsystems Le. Antenna, ore rectification filter, Rectifier, post rectification filter. In the rectenna application, it is necessary to design an antenna with very high directive characteristics to meet the demands of long-distance links. Since the aim is to use the rectenna to transfer DC power through wireless links for a long distance, this can only be accomplished by increasing the electrical size of the antenna.

### 2.9.5 Telemedicine Application:

In the telemedicine application antenna is operating at 2.45 GHz. Wearable microstrip antenna is suitable for Wireless Body Area Network (WBAN). The proposed antenna achieved a higher gain and front to back ratio compared to the other antennas, in addition to the semi-directional radiation pattern which is referred over the omnidirectional pattern to overcome unnecessary radiation to the user's body and satisfies the requirement for on-body and off-body applications. An antenna having a gain of 6.7 dB and an F/B ratio of 11.7 dB and resonates at 2.45GHz is suitable for telemedicine applications.

### 2.9.6 Medicinal Application:

It is found that in the treatment of malignant tumors the microwave energy is said to be the most effective way of inducing hyperthermia.The design of the particular radiator which is to be used for this purpose lightweight, easy in handling, and to be rugged. Only the path radiator fulfills these requirements. The initial designs for the Microstrip radiator for inducing hyperthermia were based on the printed dipoles and annular rings which were designed on S-band. And later on, the design was based on the circular microstrip disk at L-band. There is a simple operation that goes on with the instrument; two coupled Microstrip lines are separated with a flexible separation which is used to measure the temperature inside the human body.

# 3. Design of Conventional Rectangular Microstrip Patch Antenna

## 3.1 Introduction

The most commonly employed microstrip antenna is a rectangular patch which looks like a truncated microstrip transmission line. It is approximately of one-half wavelength long. When air is used as the dielectric substrate, the length of the rectangular microstrip antenna is approximately one-half of a free-space wavelength. As the antenna is loaded with a dielectric as its substrate, the length of the antenna decreases as the relative dielectric constant of the substrate increases. The resonant length of the antenna is slightly shorter because of the extended electric "fringing fields" which increase the electrical length of the antenna slightly. An early model of the microstrip antenna is a section of microstrip transmission line with equivalent loads on either end to represent the radiation loss.

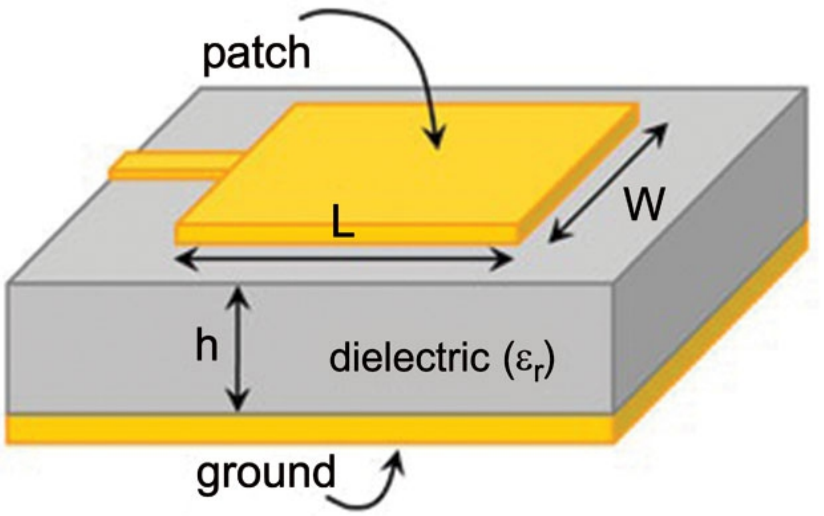


Fig.3.1: Rectangular Microstrip Patch Antenna

The patch antenna, micro strip transmission line and ground plane are made of high conductivity metal (typically copper). The patch is of length *L*, width *W*, and sitting on top of a substrate (some dielectric circuit board) of thickness h with permittivity $\varepsilon_r$. All of the parameters in a rectangular patch antenna design (*L*, *W*, *h*, permittivity) control the properties of the antenna.

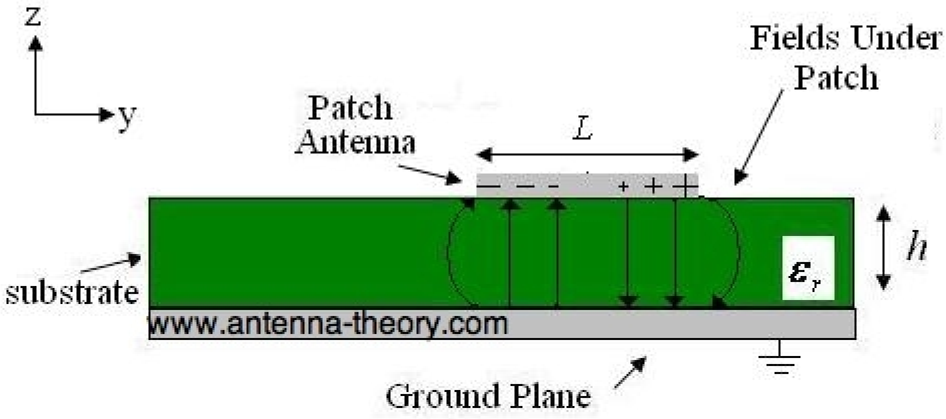


Fig.3.2: Side view of the patch antenna with fringing fields

It is the fringing fields that are responsible for the radiation. Note that the fringing fields near the surface of the patch antenna are both in the +y direction. Hence, the fringing E-fields on the edge of the microstrip antenna add up in phase and produce the radiation of the microstrip antenna. The current adds up in phase on the patch antenna as well; however, an equal current but with opposite direction is on the ground plane, which cancels the radiation. This also explains why the microstrip antenna radiates but the microstrip transmission line does not. The microstrip antenna's radiation arises from the fringing fields, which are due to the advantageous voltage distribution; hence the radiation arises due to the voltage and not the current. The patch antenna is therefore a "voltage radiator"

## 3.2 Design Equations of Rectangular Patch Antenna

**Step 1:** Calculation of the Width (W)

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r + 1)}{2}}}$$

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

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

**Step 3:** Calculation of the Effective length

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}}$$

**Step 4:** Calculation of the length extension ΔL

$$\Delta\mathrm{L} = 0.412\mathrm{h}\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

**Step 5:** Calculation of actual length of the patch

$$L = L_{eff} - 2\Delta\mathrm{L}$$

**Where the following parameters are used**

$f_0$ is the Resonance Frequency

W is the Width of the Patch

L is the Length of the Patch

h is the thickness

εr is the relative permittivity of the dielectric substrate

c is the Speed of light: 3 x $10^8$m/s

## 3.3 Conventional Rectangular Patch Antenna Design

A 5.8GHz rectangular microstrip antenna is designed. We choose the Rogers 4003 as the dielectric substrate, which has a thickness of 0.508mm. The relative dielectric constant ($\varepsilon_r$ ) is 3.36, and the loss tangent ( tan δ ) is 0.0027. The size of rectangular microstrip patch is shown in Fig.3.3.

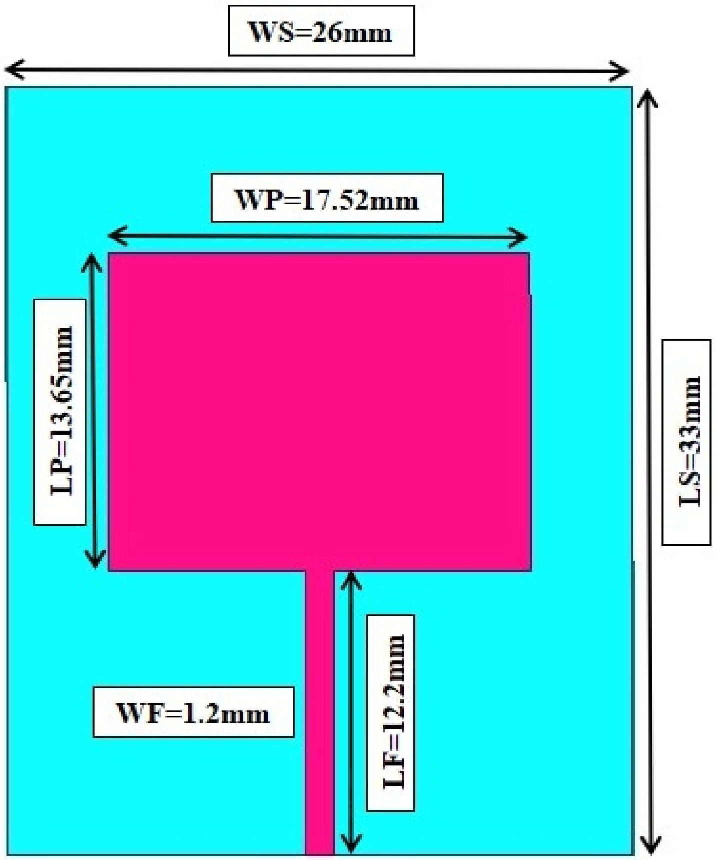


Fig.3.3: Conventional Rectangular Patch Antenna

### 3.3.1 Simulation Results

The above designed antenna is simulated using HFSS and the antenna parameters like Return Loss, VSWR,etc., were observed.

**Return loss** is the ratio of the reflected signal to the launched signal. That is, we want to have as less reflected signal as possible. This is because the more signal is reflected, this means we are delivering less signal to the load. Generally return loss of less than -10dB is preferred but from the Fig.3.4, we can see that the return loss is greater than -10dB. The above designed antenna is operating at 5.84GHz frequency with a return loss of -4.22dB.

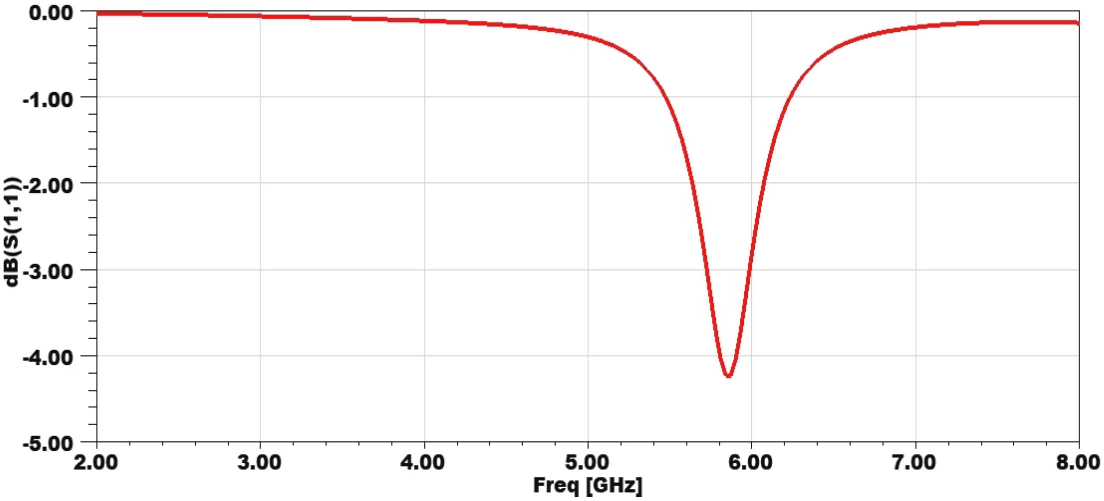


Fig.3.4: Return Loss for Conventional rectangular patch antenna

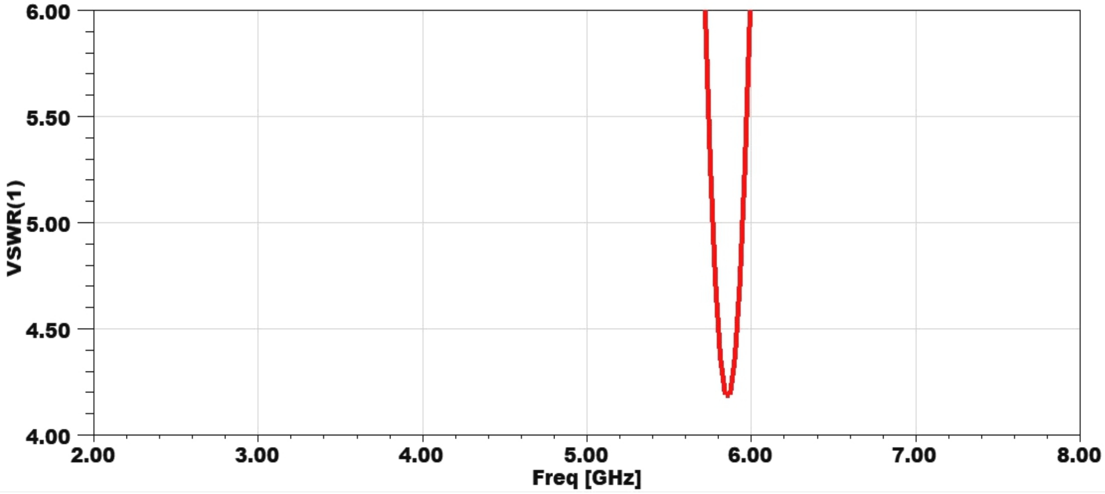


Fig.3.5: VSWR for Conventional rectangular patch antenna

**VSWR** (Voltage Standing Wave Ratio), is a measure of how efficiently radio-frequency power is transmitted from a power source, through a transmission line, into a load. The range of values for VSWR is from 1 to ∞ . A **VSWR** value **under 2** is considered suitable for most antenna applications. But, here we can see from Fig.3.5, that the VSWR is greater than 2 i.e., 4.19 at 5.84GHz frequency.

## 3.4 Quarter Wave Transformer

We can see that the above results were not acceptable as the return loss is greater than -10dB. This is due to improper impedance matching of the feed line and the patch. So as to overcome this problem, we have introduced a quarter wave transformer in the design

.Impedance transformer allows perfect matching of two different systems. If the load in the system does not match with the source, then due to reflection from load; standing wave patterns are generated and complete power is not transferred to the load instead it gets stored. This stored power can damage and overheat the system when delivered back to the input source. A **quarter-wave transformer** is a simple impedance transformer which is commonly used in **impedance matching** in order to minimize the energy which is reflected when a transmission line is connected to a load. The quarter-wave transformer uses a transmission line with different characteristic impedance and with a length of one-quarter of the guided-wavelength to match a line to a load. The quarter-wave transformer provides narrow-band impedance matching by giving zero reflection at the operating frequency. However, broadband matching is strongly desired in many applications. This problem can be solved by multi-section matching transformer and Tapered lines. Multi-section matching transformer increases the impedance bandwidth with the increased number of sections.

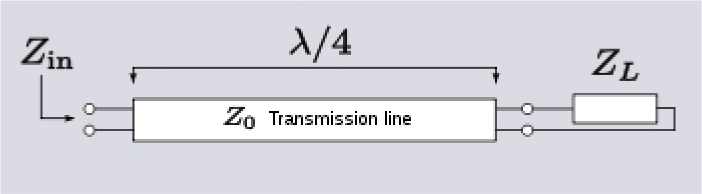


Fig.3.6: Quarter Wave Transformer

The relationship between the characteristic impedance, $Z_0$, input impedance, $Z_{in}$ and load impedance, $Z_L$ is:

$$Z_o = \sqrt{Z_L Z_{in}}$$

The dimensions of a quarter wave transformer depend on two main parameters: the impedance to match and the dielectric characteristics. Supposing to match an impedance Zin and the load $Z_L$, the impedance of the quarter wave transformer is $Z_0^2 = Z_L * Zin$. For example if Zin = 50ohm and $Z_L$ = 100 Ohm the impedance is 70.7 ohm. Established the impedance you have to design the width as function of the dielectric characteristics (dielectric constant, dielectric height, loss tangent,...) and the length as function of your wavelength.

The input impedance i.e., feed line impedance, is generally considered as 50Ω or 75Ω.

$\mathbf{Z_{in} = 50\Omega}$

The impedance of the patch is calculated using the formula

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

Where L and W are the length and width of the patch respectively and $\varepsilon_r$ is the relative permittivity of the substrate.

The characteristic impedance is calculated using the formula

$$\mathbf{Z_0 = \sqrt{Z_L Z_{in}}}$$

Width of quarter wave transformer can be calculated by putting the value Zq and solving it for $W_1$

$$Z_q = \frac{60}{\sqrt{\varepsilon_r}} \ln\left(\frac{8d}{w_1} + \frac{w_1}{4d}\right)$$

Length $L_1$ of the quarter wave transformer is calculated using the formula

$$L_1 = \frac{\lambda_g}{4\sqrt{\varepsilon_{re}}}\,.$$

Width of 50Ω microstrip feed can be found using the formula:

$$If\ \left(\frac{W}{H}\right) < 1:$$

$$\varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{H}{W}\right)}} + 0.04\left(1-\left(\frac{W}{H}\right)\right)^2\right]$$

$$Z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}}\ln\left(8\left(\frac{H}{W}\right) + 0.25\left(\frac{W}{H}\right)\right)$$

$$If\ \left(\frac{W}{H}\right) > 1:$$

$$\varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \left[\frac{\varepsilon_R-1}{2\sqrt{1+12\left(\frac{H}{W}\right)}}\right];\ \ Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{W}{H}+1.393+\frac{2}{3}\ln\left(\frac{W}{H}+1.444\right)\right]}$$

Where W is the feed width and H is the substrate thickness

## 3.5 Design of the Conventional Rectangular Patch Antenna using Quarter Wave Transformer

A rectangular microstrip patch antenna with QWT operating at 5.8GHz is designed. We have chosen the Rogers 4003 as the dielectric substrate, which has a thickness of 0.508mm. The relative dielectric constant ($\varepsilon_r$ ) is 3.36, and the loss tangent ( tan δ ) is 0.0027. The size of rectangular microstrip patch is shown in Fig.3.7.

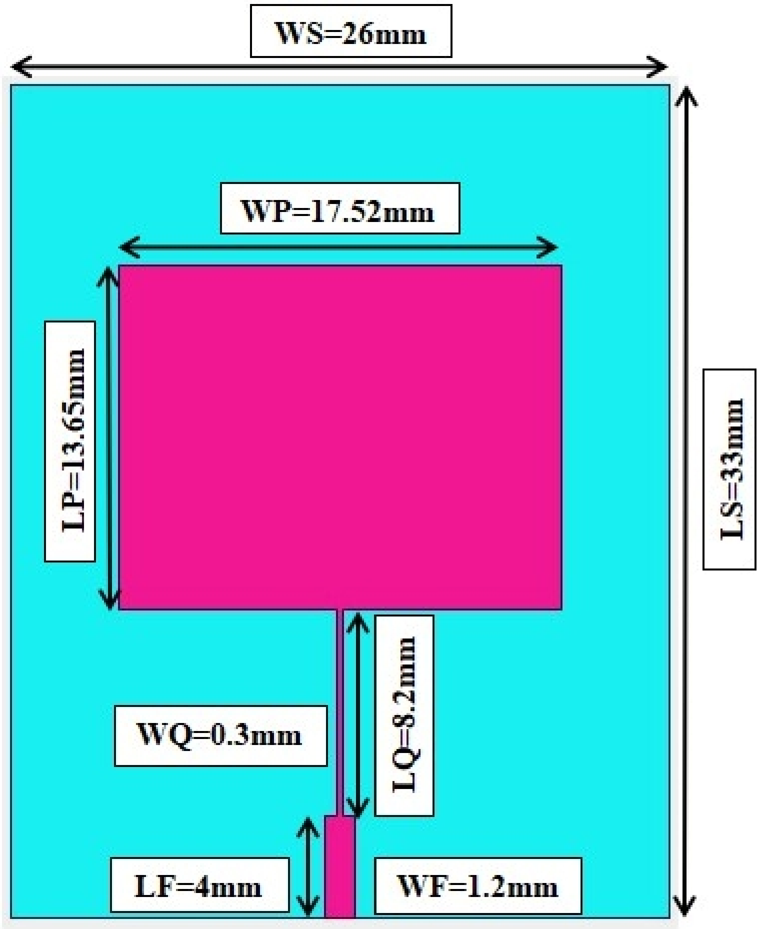


Fig.3.7: Conventional Rectangular Patch Antenna with QWT

### 3.5.1 Simulation Results

The above designed antenna is simulated using HFSS and the antenna parameters like Return Loss, VSWR,etc., were observed.

We know that the return loss should be less than -10dB for a good antenna. When quarter wave transformer is used, the impedance is perfectly matched as we can see in Fig.3.8, that the return loss is -23.04dB at 5.81GHz frequency.

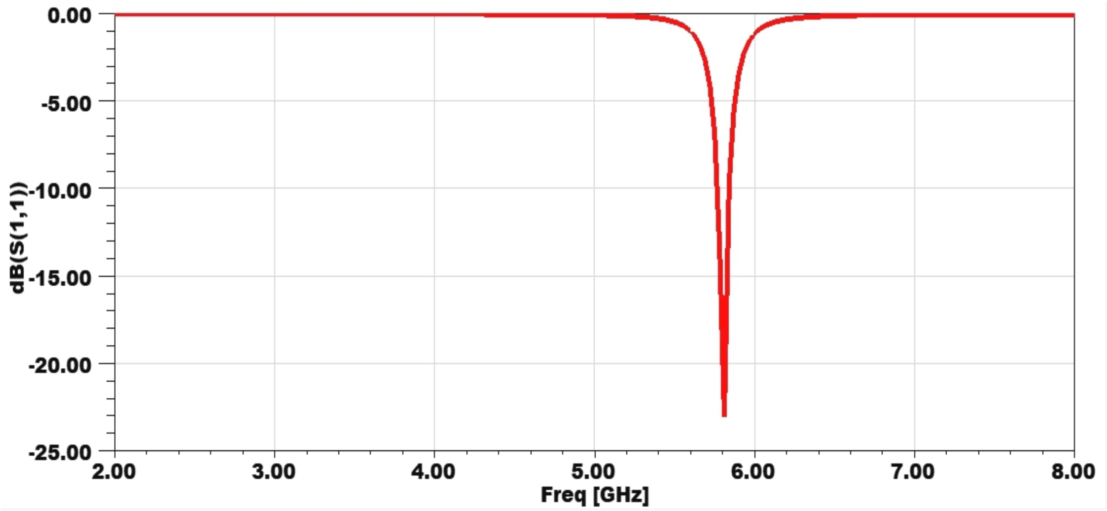


Fig.3.8: Return Loss for the conventional rectangular patch antenna with QWT

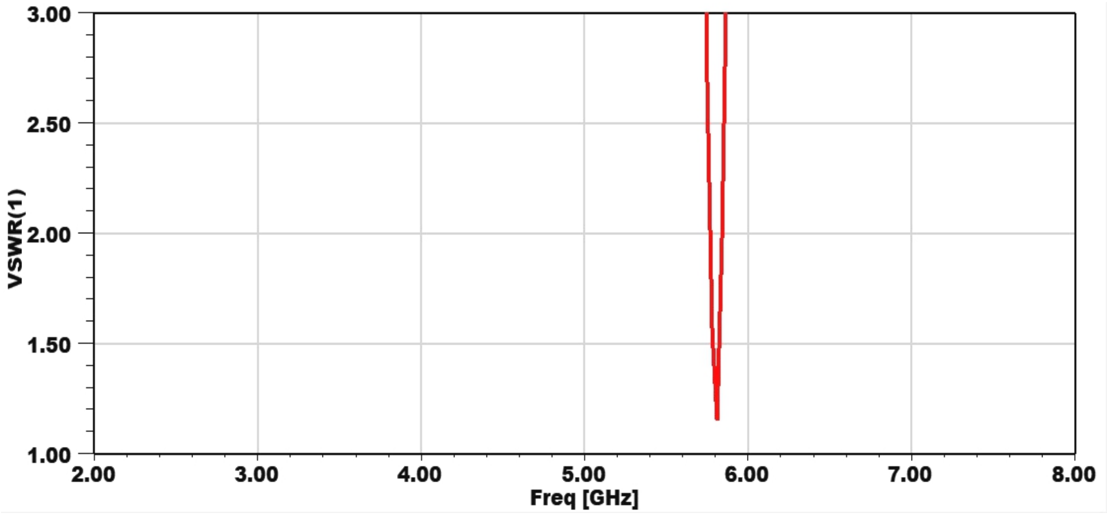


Fig.3.9: VSWR for the conventional rectangular patch antenna with QWT

For a practical antenna, VSWR of value less than 2 is acceptable. We can observe from the Fig.3.9, that the antenna is operating at 5.81GHz frequency with VSWR=1.15.

By comparing the results of both the designs, we can say that the antenna with quarter wave transformer produced better results than the one without. This is because the impedance is perfectly matched in case of antenna with the quarter wave transformer.

# 4. Miniaturization of Rectangular Microstrip Patch Antenna

## 4.1 Introduction

Microstrip patch antenna (MPA) has become an integral part of wireless communication system because of their advantages such as low profile, light weight, available with planner and non-planner structure. The increasing growth of wireless system requires miniaturized antenna. Conventional antenna size is about half wavelength. With the development of the technologies wireless systems becoming more and more compact so antenna size must have been reduced.This miniaturization techniques include use of high permittivity ϵr materials, use of meta- materials, Sierpinski carpet fractal method, using pins between patch and ground plane, introducing slots in the patch.

Miniaturization of an antenna is topic of interest for a long time. Most of the study concluded that reducing the size of antenna gain and bandwidth also reduce by some fraction. It has been well known that there is a theoretical lower limit on Q factor that can be achieved for antenna. Theoretical lower bound of Q-factor can be given by

$$\mathbf{Q}= \frac{1}{Ka}+\frac{1}{(Ka)^3}$$

Where '$K_a$' is wave number and given expression is valid for lossless antenna. It shows that by decreasing the size of antenna Q factor increases so antenna performances reduces. So Q can be reduce at the expense of the antenna efficiency and gain of antenna. Basically there are two methods to miniaturize microstrip patch antenna. The first method is to change the properties of substrate such that effective wavelength in the substrate is reduced. The second method is to increase the electrical path for current flowing.

## 4.2 Miniaturization Methods

### 4.2.1 Use of High permittivity material

The easiest way to reduce the size of patch antenna is to use high dielectric constant (ϵr) material. Antenna dimensions such as length and width are inversely proportional to the square root of relative permittivity of the substrate material. By using higher dielectric constant materials surface wave propagation will increase within the substrate and results in lower radiation efficiency because of increased losses and also bandwidth will decrease. Size reduction in the ground plane results poor polarization as well as changes the performance characteristics of patch antenna. Various studies have investigated different materials as well as configurations to effectively use the above approach to miniaturize an MPA.

### 4.2.2 Use of Sierpinski carpet fractal method

The space-filling property of the fractal causes effectively increase the electrical length which is used to reduce the size of the antenna. Sierpinski carpet fractal method with different iterations was used to reduce the size of the patch of the microstrip patch antenna.In this design initially patch was divided into nine congruent rectangles and central rectangle was removed. In the further iterations remaining eight rectangle were again divided into another nine congruent rectangles and from these rectangles again central rectangle was removed. This similar procedure was followed for other iterations. This design was not printed for the whole part of design. The part containing feed line was not disturbed by the Sierpinski carpet fractal to get better impedance matching. The iterative process was based on the following rules:

$$\mathbf{N_n = 8^n}$$

$$\mathbf{L_n} = \left(\frac{1}{3}\right)^{n}$$

$$\mathbf{A_n} = \left(\frac{8}{9}\right)^{n}$$

Where Nn is the number of rectangles covering the radiating material, Ln is the length ratio, An is the ratio for fractal area.

### 4.2.3 Use of shorting pins between patch and ground plane

By using the shorting pins between the patch and ground plane size reduction of antenna can be achieved because it makes antenna electrically small. With respect to transmission line model, for a half wavelength rectangular patch antenna E-field distribution is maximum at the radiating edges and zero at the middle. So we can remove the one half of that distribution and also can get the same Q performance at the same resonant frequency that is called quarter wavelength antenna. By introducing shorting pins between patch and ground plane higher size reduction achieved but directivity was reduced and hence antenna gain was also reduced.

### 4.2.4 Introducing slots in the patch method

Changing the shapes of the patch or introducing the slots on the patch is commonly used technique to miniaturize the microstrip patch antenna. By introducing the slots or changing the slots, electrical paths for current increases. Miniaturization using this method suffers from ohmic losses and that causes reduction in the antenna gain and radiation efficiency for microstrip patch antenna.

### 4.2.5 Use of Meta-materials

Meta-materials are artificially engineered materials to have a properties which are not readily available. Metamaterials are having negative values of permittivity and permeability. Materials with only negative permittivity is called as ϵ-negative and materials with only negative permeability is called as μ-negative. Materials with both permittivity and permeability negative is called as double-negative. This kind of structure used to achieve high antenna performance and improved radiation efficiency. Also they can be used for miniaturization of patch antenna.

## 4.3 I-shaped Resonant-ring Design

The I-shaped resonator ring as shown in Fig.4.1, can form negative permittivity and negative permeability. The different combinations of the size have different effects on microstrip antennas. In order to analyze the influence of I-shaped resonator-rings with various sizes on the microstrip antenna miniaturization, we use HFSS to simulate the model. Through the simulation analysis, we get the S parameters and resonant frequency of the I-shaped resonant-ring with different sizes.

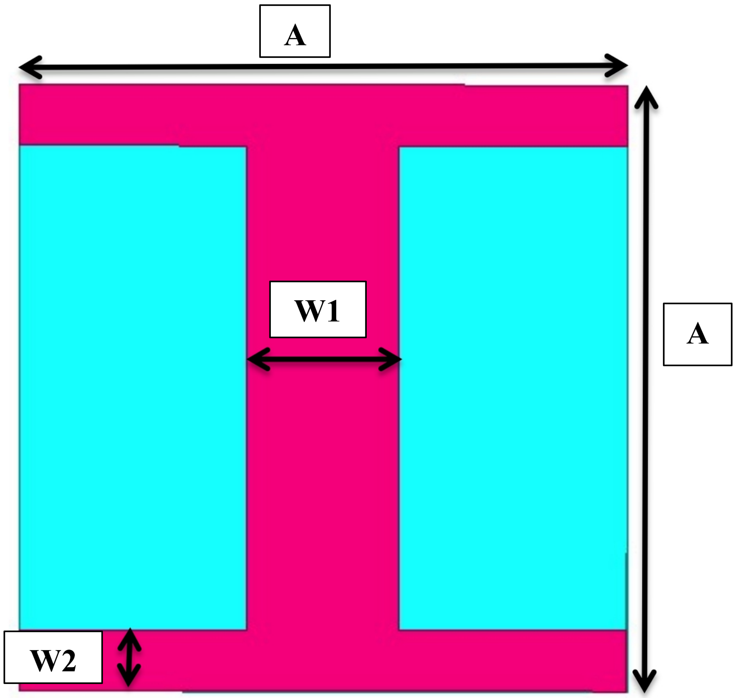


Fig.4.1: I-shaped resonant ring model

## 4.3.1 Parametric Analysis

### 4.3.1.1 Analysis of resonant-ring length

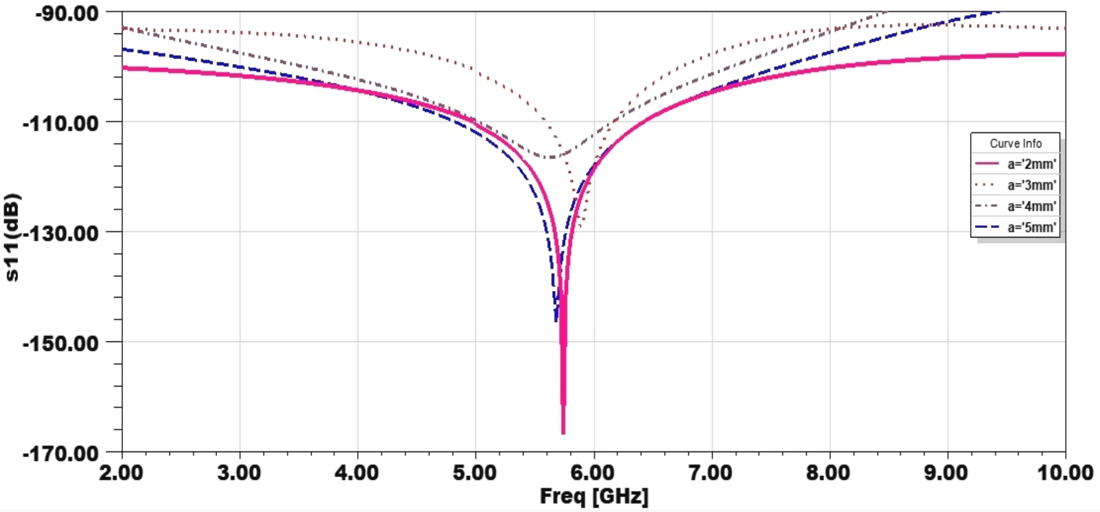


Fig.4.2: Changes of I-shaped resonant-ring resonant frequency with the side “a”

The parametric sweep of the resonant ring length(a) is shown in the fig.4.2 The length a is varied from 2mm to 5mm. We can see that the frequency varies with change in the length a.The lower the resonant frequency of the etched metamaterial, the greater the capacitance with series connection. So the antenna miniaturization can be achieved by increasing the resonant frequency. In consideration of the number of resonant-rings, the optimum length of I-shaped resonant-ring is set to be 2mm.

### 4.3.1.2 Analysis of longitudinal microstrip line width

The change of I-shaped resonant-ring resonant frequency with the longitudinal microstrip line width w1 is shown in Fig.4.3 When w1 changes from 0.3mm to 0.6mm (other parameters remain unchanged), the corresponding resonant frequency and S11 are shown with w1 being 0.3mm, 0.4mm, 0.5mm, and 0.6mm, respectively. We can get from Fig. that the resonant frequency and S11 of I-shaped resonant-ring are almost independent of w1 . The longitudinal microstrip line width w1 is set to be 0.5mm.

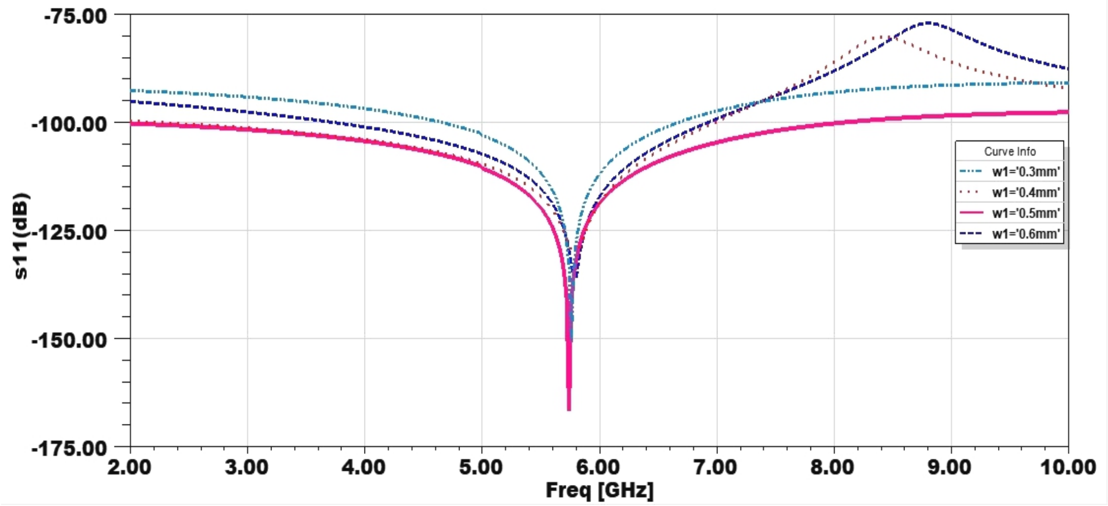


Fig.4.3: Changes of I-shaped resonant-ring resonant frequency with “ w1 ”

### 4.3.1.3 Analysis of transverse microstrip line width

The change of I-shaped resonant-ring resonant frequency with the transverse microstrip line width w2 is shown in Fig.4.4. When w2 changes from 0.1mm to 0.3mm (other parameters remain unchanged), the corresponding resonant frequency and S11 are shown with w2 set to be 0.1mm, 0.15mm, 0.2mm, 0.25mm, and 0.3mm, respectively.

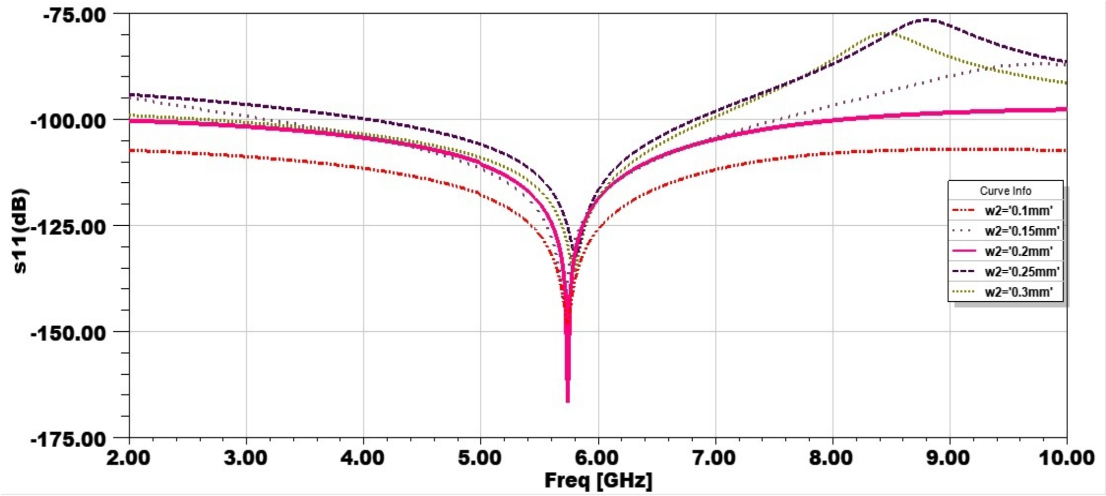


Fig.4.4: Changes of I-shaped resonant-ring resonant frequency with “ w2 ”

As shown in Fig.4.4, the change of the resonant frequency with w2 is very small. In this design, we have chosen w2=0.2mm as the width of the transverse microstrip line.

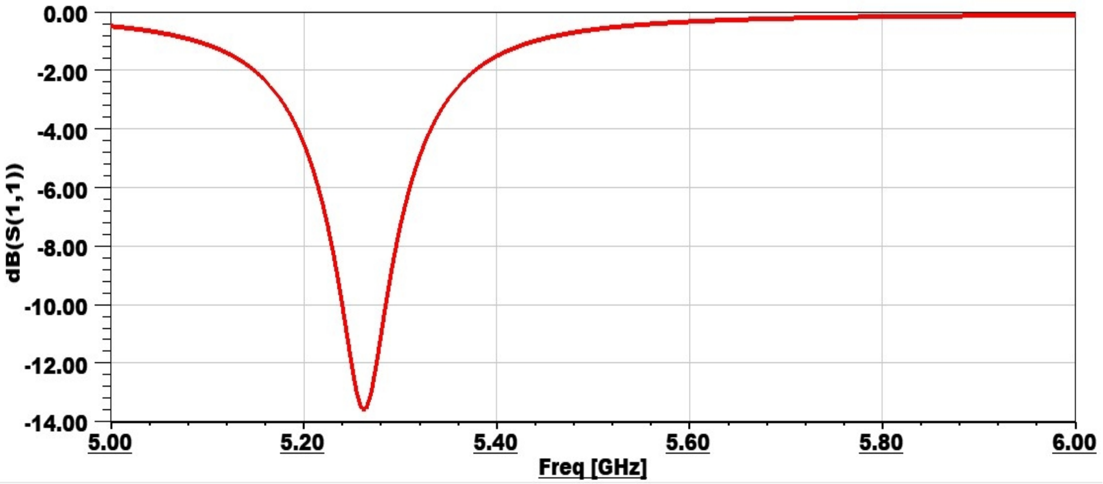


Fig.4.5: Return Loss when 15 I-shaped resonant rings are embedded on patch

Through the analysis of the I-shaped resonant-ring, we choose the resonant-ring with a= 2mm , w1= 0.5mm , w2= 0.2mm to etch on the rectangular microstrip antenna. The resonant frequency is reduced by an equivalent capacitance in series connection. The higher the number of the structure etched, the larger the equivalent capacitance in series connection, and the lower the resonant frequency of the microstrip antenna. When the antenna is etched 15 I-shaped resonant-rings, the resonant frequency is reduced to 5.26GHz and the frequency decreased by 0.54GHz. The |S11| of microstrip antenna decreases with the number of resonant-rings. The reason is that the input impedance of the microstrip antenna has changed after etching, and it cannot be kept at 50Ω. Therefore we need to realize the impedance matching again.

## 4.4 Miniaturized Antenna Design

In our work, miniaturized patch antenna is designed by etching 15 I-shaped resonant-rings. Under the condition of maintaining the bandwidth and the maximum gain, the overall size of the antenna designed at 5.8GHz is reduced by 34.3% comparing with the conventional rectangular patch antenna.

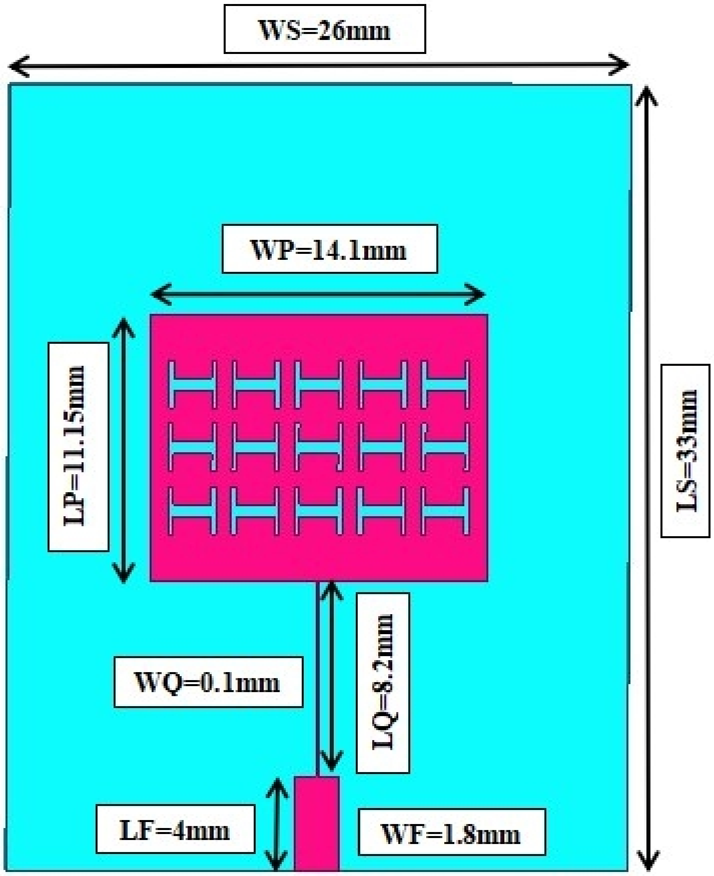


Fig.4.6: Miniaturized Antenna Model

On the basis of etching a plurality of I-shaped resonant-rings on rectangular microstrip antenna, we can reduce the physical size of the antenna and increase the resonant frequency. After adjustment and optimization, we get a well matched rectangular microstrip antenna at 5.8GHz. The size of the rectangular microstrip antenna etched with

15 I-shaped resonant-rings is reduced from 13.65mm x 17.52mm to 11.15mm x 14.1mm. The size of the antenna is reduced by 34.3% compared to the original patch, which realizes significant size reduction.

### 4.4.1 Simulation Results

The above designed antenna is simulated using HFSS and the antenna parameters like Return Loss, VSWR, Radiation Pattern,etc., were observed.

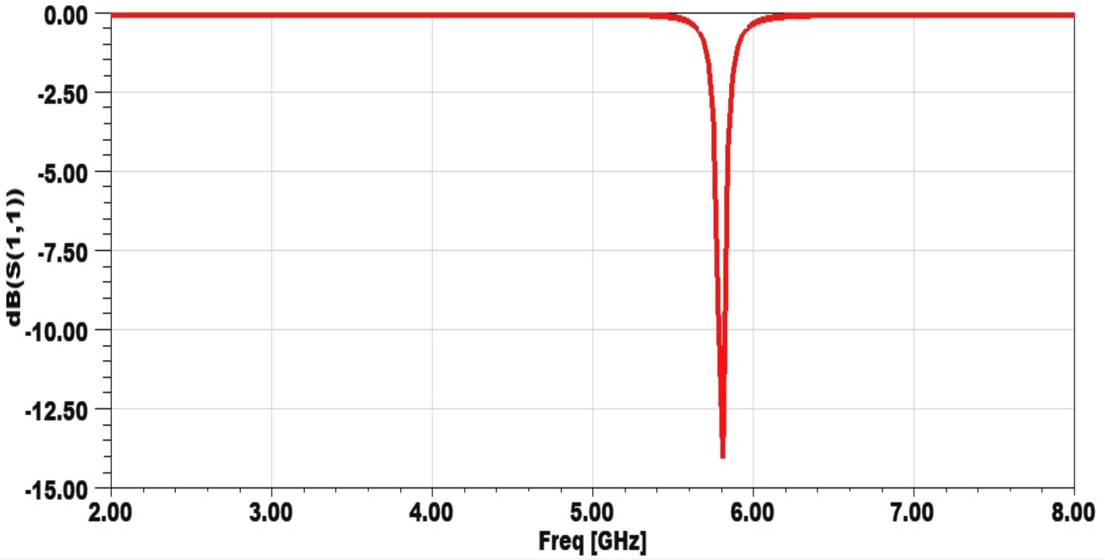


Fig.4.7: Return Loss of the Miniaturized Antenna

The Return Loss and the VSWR are portrayed in Fig.4.7 and Fig.4.8 respectively. We can observe that the miniaturized antenna is operating at 5.8GHz frequency with a return loss of -14.04dB and, VSWR at that frequency is 1.49.

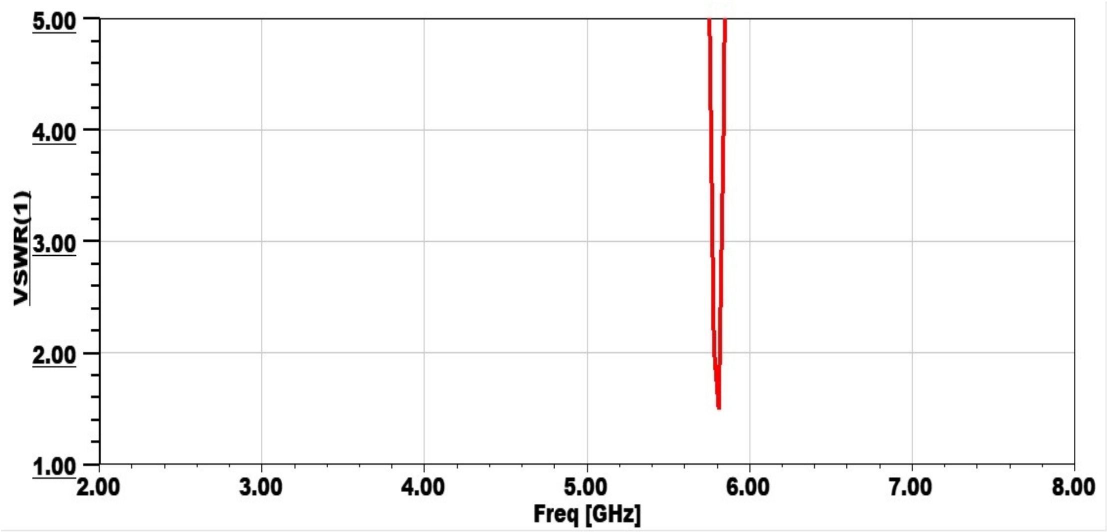


Fig.4.8: VSWR of the Miniaturized Antenna

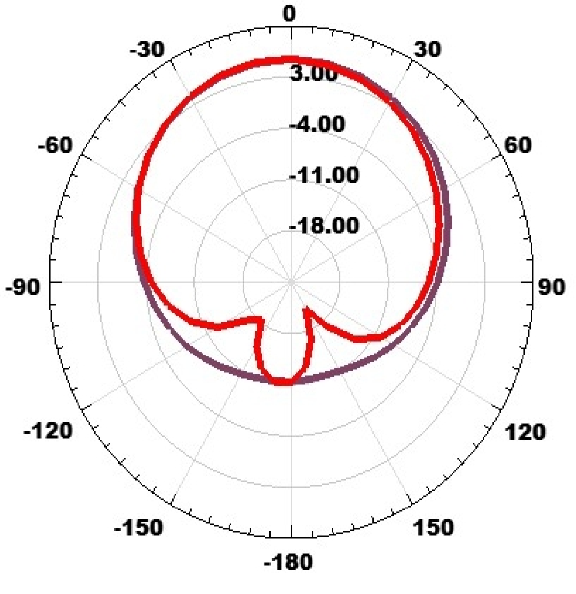


Fig.4.9: Radiation Pattern of the Miniaturized Antenna

# 5. Ultra-wide Band Technology

## 5.1 Introduction

Ultra-wide band also is known as UWB, and the ultra band is a radio technology that can use a very low energy level for short-range, high-bandwidth communications over a large portion of the radio spectrum. UWB has traditional applications in non cooperative radar imaging. Most recent applications target sensor data collection, precision locating, and tracking applications. Unlike the spread spectrum, UWB transmits in a manner that does not interfere with conventional narrowband and carrier wave transmission in the same frequency band.

Ultra-Wide Band (UWB) communication systems have the promise of very high bandwidth, reduced fading from multi-path, and low power requirements.It 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 efficient use of radio bandwidth while enabling high-data-rate personal area network (PAN) wireless connectivity, long-range, low-data-rate applications, and radar and imaging systems.

Ultra-wide band was formerly known as pulse radio, but the FCC and the International Telecommunication Union Radio communication Sector (ITUR) currently define UWB as an antenna transmission for which emitted signal bandwidth exceeds the lesser of 500 MHz or 20% of the arithmetic center frequency. Thus, pulse-based systems-where each transmitted pulse occupies the UWB bandwidth (or an aggregate of at least 500 MHz of the narrow-band carrier; for example, orthogonal frequency-division multiplexing (OFDM) can access the rules. Pulse repetition rates may be either low or very high. Pulsebased UWB spectrum under radars and imaging systems tend to use low repetition rates (typically in the range of 1 to 100 mega pulses per second). On the other hand, communications systems favor high repetition rates (typically in the range of one to two Giga pulses per second), thus enabling short-range gigabit-per-second communications systems. Each pulse in a pulse-based UWB system occupies the entire UWB bandwidth. This allows UWB to reap the benefits of relative immunity to multi-path fading, unlike carrier-based systems which are subject to deep fading and inter-symbol interference. However, both systems are susceptible to inter symbol interference.

A significant difference between conventional radio transmissions and UWB is that conventional systems transmit information by varying the power level, frequency, and/or phase of a sinusoidal wave. UWB transmissions transmit information by generating radio energy at specific time intervals and occupying large bandwidth, thus enabling pulse-position or time modulation. The information can also be modulated on UWB signals (pulses) by encoding the polarity of the pulse, its amplitude, and/or by using orthogonal pulses. UWB pulses can be sent sporadically at relatively low pulse rates to support time or position modulation, but can also be sent at rates up to the inverse of the UWB pulse bandwidth. Pulse UWB systems have been demonstrated at channel pulses rates in excess of 1.3 Giga pulses per second using a continuous stream of UWB pulses (Continuous Pulse UWB or C-UWB), supporting forward error correction encoded data rates in excess of 675 M bit/s.

A valuable aspect of UWB technology is the ability of a UWB radio system to determine the time of flight" of the transmission at various frequencies. This helps overcome multi-path propagation, as at least some of the frequencies have a line-of-sight trajectory. With a cooperative symmetric two way metering technique, distances can be measured to high resolution and accuracy by compensating for local clock drift and stochastic inaccuracy.

Another feature of pulse-based UWB is that the pulses are very short (less than 60 cm for a 500 MHz-wide pulse, less than 23 cm for a 1.3 GHz-bandwidth pulse)so most signal reflections do not overlap the original pulse, and there is no multi-path fading of narrowband signals. However, there is still multi-path propagation and inter-pulse interference to fast-pulse systems, which must be mitigated by coding techniques.

## 5.2 History and Background

The term "Ultra-wide band" has several similar meanings such as impulse, carrier-free base-band, and large relative bandwidth radio or radar signals.The concept of Ultra-wide band technology is not new. The first pulse-based UWB spark Gap radio was developed by Guglielmo Marconi in late 1800 which was used to transmit Morse Code for several years.However, in early 1900, these radios were forbidden to use in many applications due to their strong power emission and interference with other narrowband radio systems, which were developed in the early 1900s.

In the late 1960s, UWB technology gained a lot of interest because of its use in the form of impulse radar in the military areas. During this era, significant research efforts were conducted by researchers on different aspects of Ultra-Wide band technology. In 1964 Hewlett Packard and Tektronix Inc. produced the first time domain instruments for sub nanosecond pulse diagnostics which was a huge step in UWB system design. Antennas designers such as Ramsey, Dyson, and Ross have started the design of antennas for UWB systems. Rumsey and Dyson developed logarithmic spiral antennas and Ross used impulse measurement techniques for the design of wide band radiating antenna elements. During 1960 to 1999, nearly a 40 year period, over 200 papers were published in accredited IEEE journals, and more than 100 patents were ed on topics related to UWB technology for radar and communication became Mainly, in the mid- 1980s, the FCC allocated the Industrial Scientific and Medicine (ISM) bands for unlicensed wide band communication use.Owing to this revolutionary spectrum allocation, WLAN and Wireless Fidelity (Wi-Fi) have gone through tremendous growth. It also leads the communication industry to study the merits and implications of wide bandwidth communication.

At the beginning of 2002, UWB was reborn after FCC approved the UWB technology for commercial use. UWB systems have a number of advantages over traditional narrowband systems which makes it suitable for a variety of applications including radar measurements in the time domain resolution. Attributes such as low power consumption, negligible interference to narrowband systems inherent immunity against detection and interception, strong penetration ability through different materials, etc makes UWB technology a good candidate for through-the-wall and ground-penetrating applications. This short-range, high-throughput wireless technology can transmit with data rates of 252Mbps, and a data rate of 480Mbps is expected to be achieved in the near future.

## 5.3 UWB Characteristics

### 5.3.1 Potential high-density use

UWB technology can potentially be integrated into many applications that could offer benefits to the public, consumers, businesses, and industries. For example, UWB could be integrated into applications for improved public safety through the use of vehicular radar devices for collision avoidance, airbag activation and road sensors, short-range high data rate communication devices, tagging devices, liquid level detectors and sensors, surveillance devices, location determination devices, and as a replacement for wired high data rate connections over short distances. Though most devices using UWB technology would operate at very low power, the many potential UWB applications could result in high density of devices using UWB technology in certain environments such as office and business cores.

### 5.3.2 Low Power Consumption

While transmitting data, UWB devices consume less than several tens of Micro watts. This is a huge saving and the reason is that UWB transmits short impulses constantly instead of transmitting modulating waves continuously as most narrowband systems do. UWB chip sets do not require Radio Frequency (RF) 10 Intermediate Frequency (IF) conversion, Local Oscillators, mixers, and other filters. The low power consumption makes UWB ideal for use in battery powered devices like cameras and cell phones.

### 5.3.3 High data rate

Devices using UWB technology may operate at very low power levels and can support applications involving multiple users at high data rates (e.g. short-range wireless personal area networks (WPANs) at data rates greater than 100 Mbit/s).

### 5.3.4 Interference Immunity

Due to low power and high-frequency transmission, UWB's aggregate interference is “undetected” by narrowband receivers. Its power spectral density is at or below the narrowband thermal noise floor. The low power level thus creates no irritating interference to existing home wireless systems. According to its First Report and Order, the FCC requires that indoor UWB devices transmit only when operating with a receiver. A device connected to AC power is not constrained to reduce or conserve power by ceasing transmission, so this restriction will eliminate unnecessary emissions. Additional tests conducted by the FCC have also demonstrated conclusively that UWB devices may be permitted to operate under a proper set of standards without causing harmful interference to other operations.

### 5.3.5 Secure communications

UWB signals are potentially more covert and potentially harder to detect than non UWB radio communication signals. This is because UWB signals occupy a large bandwidth, can be made noise-like, and can communicate with a unique randomizing timing code at millions of bits/s. Each bit is typically represented by a large number of pulses of very low amplitude typically below the noise level. These features result in secure transmissions with low probability of detection (LPD) and low probability of interception (LPI).

### 5.3.6 Low Complexity and Low Cost:

The most attractive of UWB advantages are of low system complexity and cost. Traditional carrier-based technologies modulate and demodulate complex analog carrier wave forms. In contrast, UWB systems are made of "all-digital" with minimal RF or microwave electronics. The inherent RF simplicity in UWB design makes the systems highly frequency adaptive and enables them to be positioned anywhere within the RF spectrum. Also, home UWB wireless devices do not need transmitting power amplifiers. This is a great advantage over narrowband architectures that require amplifiers with significant power back-off to support high-order modulation wave forms for high data rates. The cost of placing UWB technology inside a consumer electronics device is $20, compared with $40 for 802.11b and $65 for802.11a

## 5.4 UWB Power Spectra

UWB signals generated by basic pulse position modulation have numerous spectral peaks. Randomization is used to make the signal more noise-like. The shape of the power spectral density of an emitted UWB signal is usually controlled by an appropriate choice of the pulse shape, modulation technique, timing jitter, and pseudo-noise code sequences used for randomization of the UWB pulses. The spectral shape of a UWB transmission is additionally defined by components such as antennas.

## 5.4.1 Requirement for a large bandwidth

UWB transmissions spread over a very large frequency bandwidth in comparison with non UWB transmissions. Among the challenges is finding a suitable spectrum and a way to introduce UWB applications without causing interference into radio communication services.

## 5.4.2 Pulse shaping

Pulse shaping enables control of the frequency content of the UWB transmission, which can reduce interference into radio communication systems. It is fundamental that pulse shapes for UWB communications must have a zero-mean because an antenna cannot radiate signals at zero frequency. Creative designs of pulse shapes and a variety of modulation options can be incorporated in UWB communication system designs.

## 5.4.3 UWB Modulations

For UWB pulses, information can be coded using pulse position modulation (i.e. binary or M-ary PPM), PAM (i.e. binary or M-ary PAM), bi-phase modulation of pulse polarity (i.e. BPM), modulation by a doublet of a positive pulse followed by a negative pulse or vice versa, and pulse on-off keying (OOK). Furthermore, combinations of these modulations can be used. As an example, a hybrid bi-phase and PPM modulation scheme has been shown to eliminate discrete components of the UWB PSD.

UWB signal transmission involves pulse shaping, spreading, modulation, and randomization. Appropriate hybrid modulation and randomization of a UWB signal makes its spectrum appear like additive white Gaussian noise. The choice of the UWB modulation scheme impacts the power spectral density of the radiated signal and consequently its impact on radio communication services. In particular, the impact of the discrete components of the PSD can be mitigated or they can be eliminated.

### 5.4.3.1 Pulse position modulation (PPM)

PPM is a UWB modulation technique by which data are represented by time shifts from a reference time. Binary PPM has been a popular early choice and appears relatively early in the literature on UWB communications. PPM modulated UWB signals may have discrete spectra that carry no information, and may cause interference. This can be greatly mitigated by randomizing the positions of the pulses using pseudo-noise sequences, which whitens the spectrum significantly. This randomization for PPM has often been called time hopping (TH). Another way to reduce the interference from PPM UWB signals is to increase the period of the pulse train. This decreases the frequency of occurrence of discrete components of the PSD.

One form of a pulse position modulation is multi-band impulse (MB-I) UWB which comprises a method whereby the spectrum is divided into sub-bands. Impulses of very short duration are sent in frequency and time-hopped sequences over several sub-bands. Polarity or bi-phase modulation of data is used with the time-frequency hopped impulses. A multidimensional modulation space may be employed by filling out a matrix of time and frequency with impulses. Complex and efficient (with respect to Eb/N0) coherently detected modulations are also possible. The noise-like quality of the signal results from the time-frequency hopping.

#### 5.4.3.2 Bi-phase modulation (BPM)

For a binary phase modulation, a specific pulse shape and its negative are used to represent a zero and a one. BPM yields an advantage of 3 to 6 dB over PPM in multi-path free environments. It also has a peak power to average power ratio of less than 3 (compared to a sine wave with a ratio of 2).

#### 5.4.3.3 Pulse amplitude modulation (PAM)

PAM is a technique that varies the amplitude of the transmitted pulses based on the data to be transmitted. In PAM modulated devices a set of amplitudes is selected to represent the data to be transmitted. A pulse of any shape with a mean of zero may have its amplitude modulated with 1 variations (binary signalling) or M variation (M-ary PAM). PAM signals may be demodulated with non-coherent techniques.

#### 5.4.3.4 On-off keying (OOK) modulation

OOK is a special case of PAM UWB modulation wherein the presence or absence of a pulse within a time slot represents a one or a zero.

#### 5.4.3.5 Chirp modulated UWB

In chirp modulation, the carrier frequency is swept over a very wide band during a given pulse interval. The sweep pattern, which encodes the data, may be linear or non-linear according to the device requirements.

#### 5.4.3.6 Modulation by a pair of opposite polarity doublets

A doublet consisting of a positive pulse followed by a negative pulse, or vice versa, provides another form of modulation. An advantage of this type of modulation is that the choice of separation between pulses in a doublet and the time separation between doublets enables the frequency spectrum to be shaped to mitigate interference.

#### 5.4.3.7 Direct sequence and direct sequence code-division multiple access (DS-CDMA)

UWB Direct sequence ultra-wide band (DS-UWB) uses high-duty cycle polarity coded sequences of pulses to encode data at rates in the order of hundreds of megabits to beyond a gigabit per second or more. For a fixed pulse rate, multiple pulses are used to represent a single bit, thus trading energy per bit for data rate. The UWB bandwidth of DS-UWB is a function of the sub-nanosecond pulse duration of each chip. The UWB signal is noise-like with a low probability of detection and low probability of interception. The design of a good spreading code for DS-UWB is critical for good performance in a multi-path environment. In DS-CDMA multiple users can share the same spectrum simultaneously by using suitable codes.

#### 5.4.3.8 Multiband modulation and multi-user techniques

- **Multiband orthogonal frequency division multiplexing (MB-OFDM)**

MB-OFDM structures the spectrum into several sub-bands. The data is transmitted across the bands using a time-frequency code (TFC). Within each sub-band an OFDM modulation scheme is used to convey information.

- **Frequency hopping for multiband (FH-UWB)**

In FH-UWB the signal is distributed into one of several frequency bands for a short-time period. This hopping between bands is done according to a preassigned pattern (uniform or non-uniform). A multiband system can be based on the principle of transmitting different symbols in different bands in a periodic sequence, very similar to frequency hopping. Various modes of operation can be implemented by modifying the hopping rate, symbol and number of bands.

- **Time division multiple frequency modulation for multiband**

Time division multiple frequency modulation is a modulation scheme similar to frequency hopping since it uses multibands but different because the relationship between bands. Its main advantage is that it allows one to increase the number of bits per symbol and, consequently, to reduce the symbol rate. This reduces the effect of inter symbol interference caused by delay spread.

- **Cross-band flexible multiple access for multiband**

A cross-band flexible UWB multiple access scheme for multi-piconet wireless PANs uses specially designed encoding and decoding matrices to obtain resilience against multi-user interference (MUI), accommodate various spreading alternatives, enable full multipath diversity and effect scalable spectral efficiency (from low, to medium and to high-data rates).

## 5.5 UWB Standards

A standard is a precondition for any technology to grow and develop because it makes possible the wide acceptance and dissemination of products from multiple manufacturers with an economy of scale that reduces costs to consumers. Conformance to standards makes it possible for different manufacturers to create products that are compatible or interchangeable with each other.

The ability of UWB technology to provide very high data rates for short ranges (less than 10 meters) has made it an excellent candidate for the physical layer of the IEEE 802.15.3a standard for wireless personal area networks (WPANs). However, two opposing groups of UWB developers are battling over the IEEE standard. The two competing technologies are single band and multi-band. The single-band technique, backed by Motorola/Xtreme Spectrum, supports the idea of impulse radio that is the original approach to UWB by using narrow pulses that occupy a large portion of the spectrum. The multi-band approach divides the available UWB frequency spectrum (3.1 GHz to 10.6 GHz) into multiple smaller and non-overlapping bands with bandwidths greater than 500 MHz to obey the FCC's definition of UWB signals. The multi-band approach is supported by several companies, including Staccato Communications, Intel, Texas Instruments, General Atomic, and Time Domain Corporation.

To date, several proposals from both groups have been submitted to the IEEE 802.15.3a working group, and the decision is yet to be made because both technologies are impressive and have technical credibility. The following subsections discuss the two leading candidates for the 802.15.3a standard: direct-sequence UWB (DS-UWB) and multi-band orthogonal frequency division multiplexing (OFDM).

### 5.5.1 Direct-Sequence UWB

Direct-sequence UWB is a single-band approach that uses narrow UWB pulses and time-domain signal processing combined with well-understood DSSS techniques to transmit and receive information. Fig5.1 illustrates this approach.

Data representation in this approach is based on simple bi-phase shift keying (BPSK) modulation, and rake receivers are used to capture the signal energy from multiple paths in a multi-path channel. According to the proposals sent to the IEEE 802.15.3a standardization committee by the proponents of this technology, the DS-UWB technique is scalable and can achieve data rates in excess of 1 Gbps. The technical reason behind using DS-UWB is the propagation benefits of ultra-wide band pulses, which experience no Rayleigh fading. In contrast, narrowband transmissions degrade significantly due to fading.

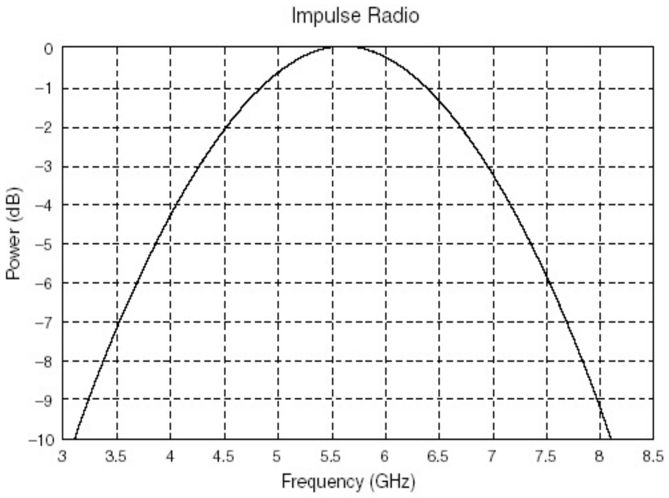


Fig.5.1: DS-UWB transmits a single pulse over a huge swath of spectrum to represent data.

### 5.5.2 Multi-band OFDM

The multi-band UWB approach uses the 7500 MHz of the RF spectrum available to UWB communications in a way that differs from traditional UWB techniques. The UWB frequency band is divided into multiple smaller bands with bandwidths greater than 500 MHz. Fig.5.2 depicts the result.

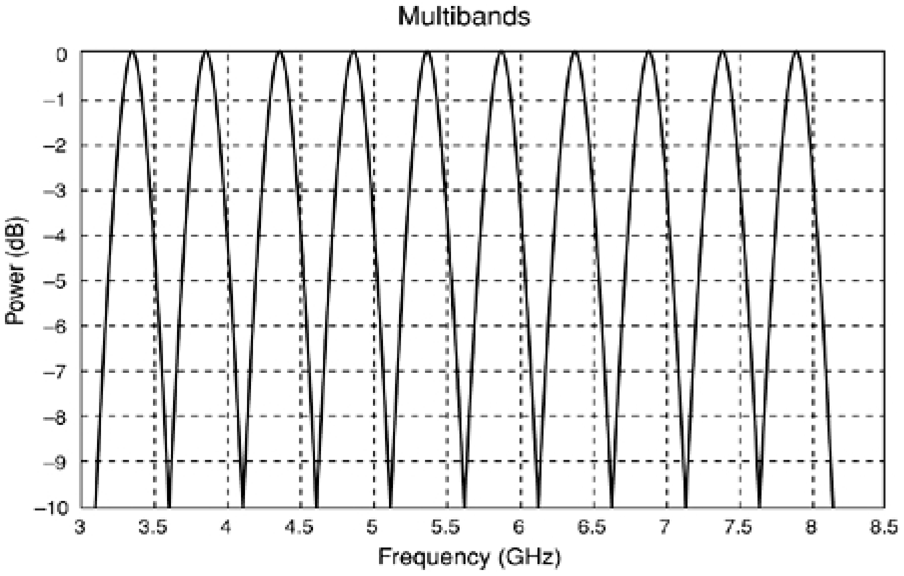


Fig.5.2: The multi-band approach divides the available UWB spectrum into several non overlapping smaller bands.

This approach is similar to the narrowband frequency-hopping technique. Dividing the UWB spectrum into multiple frequency bands offers the advantage of avoiding transmission over certain bands, such as 802.11a at 5 GHz, to prevent potential interference. In the multi-band approach, UWB pulses are not as narrow as in traditional UWB techniques; therefore, synchronization requirements are more relaxed. A variety of modulation techniques have been proposed by industry leaders for the multi-band approach; however, OFDM, which was initially proposed by Texas Instruments, offers improved performance for high-data-rate applications.

As explained briefly, both technologies are technically valid and impressive. Supporters of DS-UWB criticize the multi-band OFDM systems for their complexity, which results from using complex Fast Fourier Transforms (FFTs). On the other side, advocates of multi-band OFDM believe that their technique offers better coexistence with other radio services, and they disapprove of DS-UWB because of possible interference concerns. The debate will likely continue until the IEEE 802.15.3a standardization committee reaches a decision.

### 5.5.3 Proposed UWB Range in the world

| **Region** | **UWB Range** |
|---|---|
| United States | Single Band: 3.1GHz - 10.6GHz |
| Europe | Low Band: 3.1GHz - 4.8GHz<br>High Band: 6GHz - 8.5GHz |
| Japan | Low Band: 3.4GHz-4.8GHz<br>High Band : 7.25GHz- 10.25GHz |

Table 5.1: Proposed UWB ranges across the world

## 5.6 Advantages of UWB

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.Firstly, according to the Shannon-Hartley theorem, channel capacity is in proportion to bandwidth. Since UWB has an ultra-wide frequency bandwidth, it can achieve huge capacity as high as hundreds of Mbps or even several Gbps with distances of I to 10meters.

Secondly, UWB systems operate at extremely low power transmission levels. By dividing the power of the signal across a huge frequency spectrum, the effect upon any frequency is below the acceptable noise floor.For example, 1 watt of power spread across MHZ of spectrum results in only 1 nano watt of power into each hertz band of frequency. Thus, UWB signals do not cause significant interference to other wireless systems.

Thirdly, UWB provides highly secure and high reliable communication solutions. Due to the low energy density, the UWB signal is noise-like, which makes unintended detection quite difficult. Furthermore, the noise-like" signal has a particular shape, contrast, real noise has no shape. For this reason, it is almost impossible for real noise to obliterate the pulse because interference would have to spread uniformly across the entire spectrum to obscure the pulse. Interference is only part of the spectrum reduces the amount of received signal, but the pulse still can be recovered to restore the signal. Hence UWB is perhaps the most secure means of wireless transmission ever previously available.

Lastly, the UWB system based on impulse radio features low cost and low complexity which arise from the essential baseband nature of the signal transmission. UWB does not modulate and demodulate a complex carrier waveform, so it does not require components such as mixers, filters, amplifiers, and local oscillators.

| **Advantage** | **Benefit** |
|---|---|
| Coexistence with current narrowband and wide band radio services | Avoids expensive licensing fees. |
| Large channel capacity | High bandwidth can support real-time high-definition video streaming. |
| Ability to work with low SNRs | Offers high performance in noisy environments. |
| Low transmit power | Provides high degree of security with low probability of detection and intercept. |
| Resistance to jamming | Reliable in hostile environments. |
| High performance in multipath channels | Delivers higher signal strengths in adverse conditions. |
| Simple transceiver architecture | Enables ultra-low power, smaller form factor, and better mean time between failures, all at a reduced cost. |

Table 5.2: Advantages and Benefits of UWB

## 5.7 Applications of UWB

The major characteristics of UWB, i.e., extremely large bandwidth, low power, short-range high data rate communication, robustness against fading, immunity to multipath, multiple access capability, low cost transceivers and precise positioning, motivate several potential applications for this technology. Thus far the UWB technology has been mainly applied to military (especially radar) appliances,Adhoc Networking, Wireless sensor networks, Radio Frequency Identification or RFID, Consumer Electronics, Locating & Tracking and Medical applications.

### 5.7.1 Radar

A short-pulse UWB techniques have several radar applications such as higher range measurement accuracy and range resolution, enhanced target recognition, increased immunity to co-located radar transmissions, increased detection probability for certain classes of targets and ability to detect very slowly moving or stationary targets.UWB is a leading technology for micro air vehicles (MAV) applications. The nature of creating millions of ultra-wide band pulses per second has the capability of high penetration in a wide range of materials such as building materials, concrete block, plastic and wood.

### 5.7.2 WBAN Applications

The emerging UWB technology promises to satisfy the average power consumption requirement of the radio interface (100μW), which cannot be achieved by using narrowband radio communication, and increases the operating period of sensors. In the UWB system, considerable complexity on the receiver side enables the development of ultra-low-power and low-complex UWB transmitters for uplink communication, thereby making UWB a perfect candidate for a WBAN. The difficulty in detecting noise-like behavior and robustness of UWB signals offer high security and reliability for medical applications.A network of UWB sensors such as electrocardiogram (ECG), oxygen saturation sensor (SpO2), and Electromyography (EMG) can be used to develop a proactive and smart healthcare system. This can benefit the patient in chronic conditions and provides long term health monitoring.

### 5.7.3 Positioning and Tracking

Position location and tracking have wide range of benefits such as locating patient in case of critical condition, hikers injured in remote area, tracking cars, and managing a variety of goods in a big shopping mall. For active RF tracking and positioning applications, the short-pulse UWB techniques offer distinct advantages in precision time-of-flight measurement, multipath immunity for leading edge detection, and low prime power requirements for extended-operation RF identification (RFID) tags.

### 5.7.4 WPAN Applications

A wireless personal area network (WPAN) is a personal area network, a network for interconnecting devices centered on an individual person's workspace in which the connections are wireless. Wireless PAN is based on the standard IEEE 802.15 operating at 3.1-10.6GHz.

### 5.7.5 Wi-Fi:

Wi-Fi uses radio waves for connection over distances up to around 91 meters, usually in a local area network (LAN) environment. Wi-Fi can be used to connect local area networks, to connect cell phones to the Internet to download music and other multimedia, to allow PC multimedia content to be stream to the TV (Wireless Multimedia Adapter), and to connect video games consoles to their networks (Nintendo Wi-Fi Connection). 5.15-5.35 GHz and 5.725-5.825 GHz, are used by Wi-Fi devices.

Ultra-wide band (UWB) technology essentially enables the following wireless communication systems:

- Short-range (up to 10 m), higher data-rates (up to 1 Gbits/s) applications such as the IEEE 802.15.3a (WPAN) standard operating at 3.1-10.6 GHz;
- Long-range (up to 100m), lower data rates (up to 1 Mbits/s), e.g. wireless sensor networks operating at frequencies below 960MHz.

# 6. Design of Miniaturized Rectangular Microstrip Patch Antenna for UWB Applications

## 6.1 Introduction

The main concept behind UWB radio systems is that they transmit pulses of very short duration, as opposed to traditional communication schemes, which send sinusoidal waves. The role that UWB antennas play in all of this is that they have to be able to transmit these pulses as accurately and efficiently as possible.The UWB antenna should be consistent and predictable throughout the whole operation band. Examples include planarized and planar antennas, such as the Vivaldi antenna; volcano-smoke slot antennas; tulip-shaped monopole antennas; and many more. The tulip-shaped monopole antenna, for example, covers 2.55–32.5 GHz with fewer than -10 dB of reflection coefficient magnitude; hence, the operating band allocated by the FCC is entirely covered by this design. A few other designs also equal or approximate the FCC-allocated operating frequency band.

Some of the main features required for antennas for the application of UWB technology are as follows:

- It should have bandwidth ranging from 3.1 GHz to 10.6 GHz in which reasonable efficiency and satisfactory omnidirectional radiation patterns are necessary
- In this ultra-wide bandwidth, an extremely low-emission power level should be ensured. In 2002, the Federal Communication Commission (FCC) specified the emission limits of dBm/MHz.
- The antenna propagates short-pulse signals with minimum distortion over the frequency range.

The first point is the most important one for antenna designers, which translates into the requirement that the antenna should have an impedance bandwidth ratio of over which. Such a high impedance bandwidth is only realized using a multi resonance printed monopole antenna, which generally exhibits high pass impedance characteristics. For such broadband antennas, unlike single resonance tuned dipole or monopole antennas, some special design considerations have to be taken into account. Instead of resonance or operating frequency, lower band-edge frequency and total bandwidth achieved to become the design parameters for these printed monopole antennas. The lower band-edge frequency depends primarily on the maximum height of the monopole, whereas bandwidth of the antenna depends on how the impedance of various modes is matched with the microstrip or coplanar feed line. These parameters are discussed in detail for all the regular geometries of printed monopole antennas.

For this project, we had four main parameters that we had to satisfy. Those parameters were the bandwidth of the antenna, the VSWR of the antenna, the efficiency of the antenna, and the radiation pattern of the antenna. These parameters will help us understand if the antenna we are designing will be the optimal design for our application.

The first parameter that we had to consider for our design is the bandwidth. The bandwidth is basically the frequency (or frequencies) that the antenna is designed to radiate. In many cases, i.e. narrowband systems, the bandwidth specified for an antenna is very small because there is just one frequency that the antenna is required to radiate. In our case, we had to be able to radiate signals with frequencies between 3.86 GHz and 10.61 GHz. This required us to limit the antenna designs that we considered to strictly broadband antennas.The second parameter that we had to take in to account for our design is the VSWR of the antenna. The VSWR is defined as

$$\text{VSWR} = \frac{\boldsymbol{V}_{max}}{\boldsymbol{V}_{min}} = \frac{1+|r|}{1-|r|}$$

The voltage reflection coefficient, $\Gamma$ , is defined as

$$\Gamma = \frac{V_o^-}{V_o^+} = \frac{Z_L - Z_o}{Z_L + Z_o}$$

where $Z_L$ is the load impedance and $Z_0$ is the characteristic impedance. This reflection coefficient is also equivalent to the scattering parameter $S_{11}$. The characteristic impedance is considered to be the impedance of the antenna for our purposes. The VSWR is a way of calculating how well two transmission lines are matched. The number for the VSWR ranges from one to infinity, with one meaning that the two transmission lines are perfectly matched. In regards to antenna design, a VSWR that is as low as possible is desired because any reflections between the load and the antenna will reduce the effectiveness of the antenna.

The third parameter that we took into account for our antenna design is the efficiency of the antenna. The radiation efficiency of an antenna is defined as

$$\mathbf{e} = \frac{P_{RAD}}{P_{IN}}$$

where $\mathbf{P_{RAD}}$ is the power radiated by the antenna and $\mathbf{P_{IN}}$ is the power supplied to the antenna. The efficiency of an antenna is a measure of how much power is lost in radiating a signal from the antenna.

The fourth parameter is the radiation pattern of the antenna. This parameter is highly dependent on the application of the antenna. In the case of the antenna our group designed, we had to have an omnidirectional radiation pattern. This means that the radiation pattern had to be spread evenly 360 degrees around the antenna. The reason for this is because since the location of the transmitter is not fixed, you want to spread the radiated signal out as far as possible so the receiver will be able to pick up the transmitted signal.

One aspect of choosing a UWB antenna design that is important is ensuring that the design will not cause the pulse to spread when it is transmitted. Another aspect that is important is making sure that the antenna will be highly efficient in radiating electromagnetic energy. This is due to the fact that the transmit power used in UWB systems is very low (-41.3 dBm/MHz). Finally, the UWB antenna needs to be broadband enough to handle the bandwidth requirements for UWB (a fractional bandwidth greater than 20%).

## 6.2 Antenna Design

The design of the miniaturized rectangular patch antenna is shown in Fig.6.1. The Patch is printed on a Rogers RO4003 dielectric substrate with thickness of 0.508mm. The relative permittivity($\varepsilon_r$) of the substrate is 3.36 and the dielectric tangent loss is 0.0027.

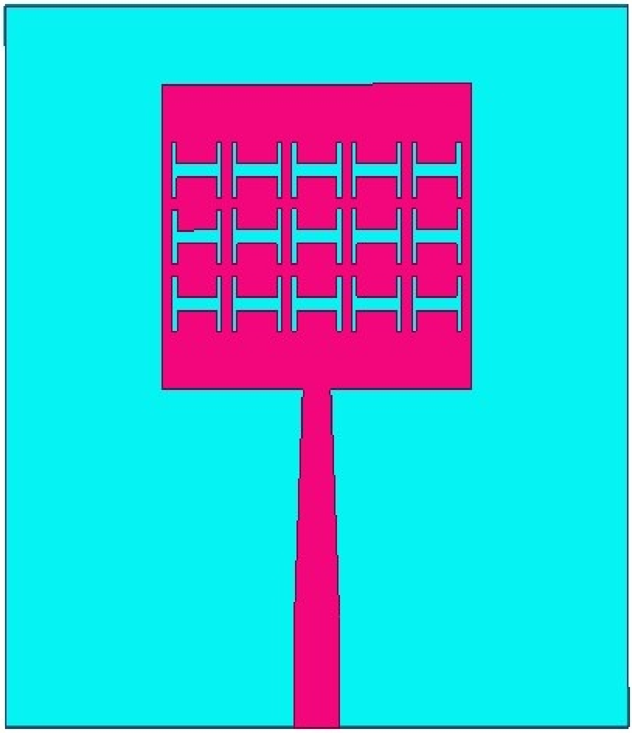


Fig.6.1: Miniaturized Rectangular Microstrip Patch Antenna with Tapered feed

## 6.2.1 Parametric Results

In parametric sweep, we simulate the antenna design for different values of a particular parameter. This is helpful in selecting the desired parameter value for the design. By selecting the best results obtained from parametric sweep, we will optimize the design.

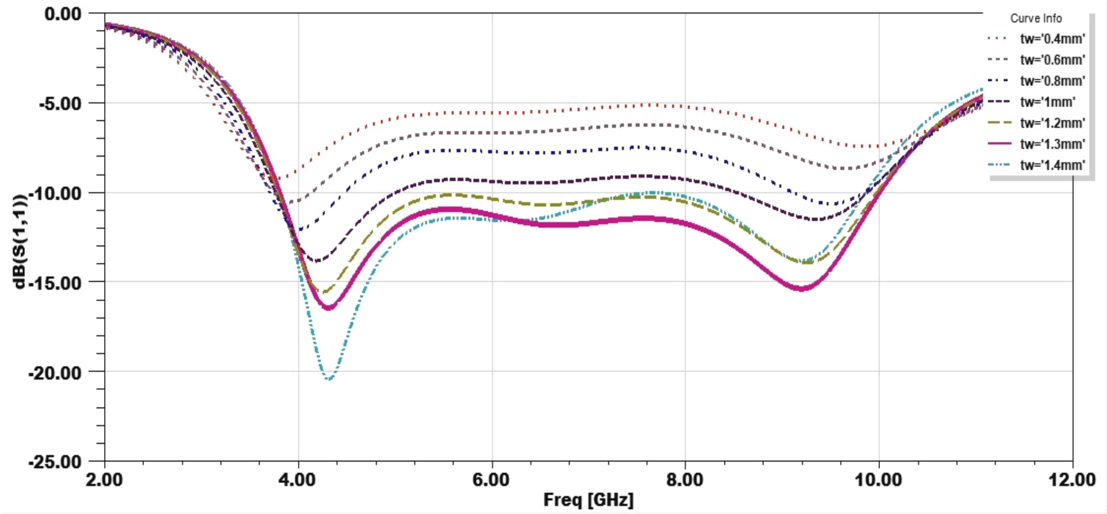


Fig.6.2: Variation of Return Loss for different widths of tapered feed

We can observe from Fig.6.2, that the return loss is changing for different widths of tapered feed. We have simulated the design by varying the width of the tapered feed from 0.4mm to 1.4mm and observed the results. For tw=1.3mm, the return loss is less than -10dB for the entire bandwidth of the proposed antenna and for the other values of tw, the impedance is not perfectly matched. For tw=1.4mm, though the impedance is matched, the bandwidth is reduced. So, the width of the tapered feed is set to 1.3mm.

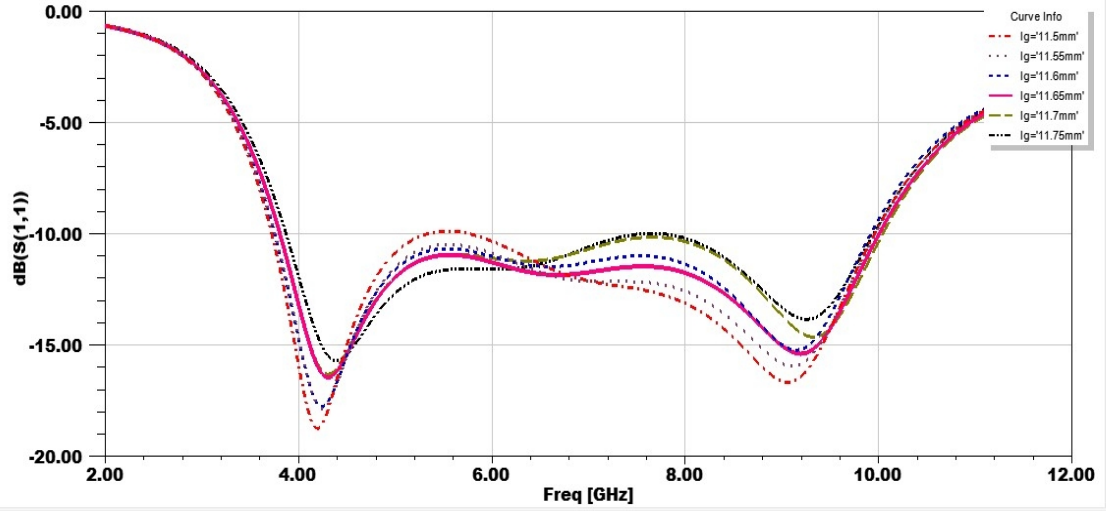


Fig.6.3: Variation of Bandwidth for different lengths of Ground Plane

The variation in bandwidth with the length of the ground plane is shown in Fig. At the point when the length of the ground plane lg changes from 11.45mm to 11.75mm, the corresponding bandwidth and return loss are shown. With the decrease in the length of the ground plane, the capacitance shrinks as the stored energy is reduced. Due to which the quality factor decreases, as a result, the bandwidth increases. The partial ground length of 11.65mm was chosen.

## 6.3 Proposed Antenna Design

After choosing the best values from the results of the parametric sweep,we have included those in the design. The modified design of miniaturized rectangular microstrip patch antenna for UWB applications is shown in the fig.6.4. The ground plane of length 11.65mm and the tapered feed of width 1.3mm were chosen from the sweep results.

By modeling the antenna with dimensions mentioned in the table 6.1, we could obtain ultra-wide band characteristics.

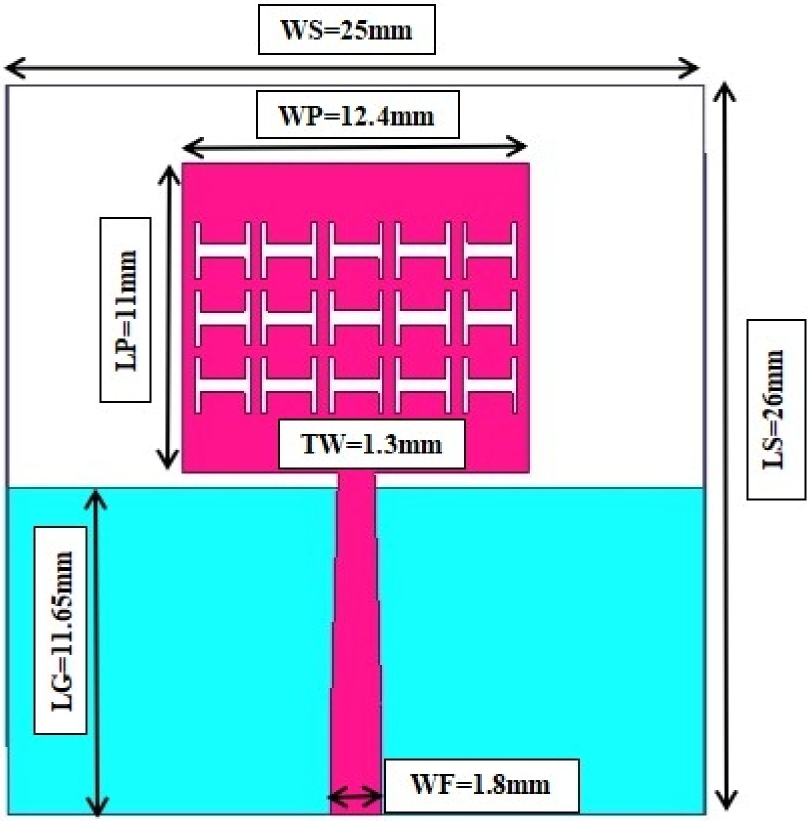


Fig.6.4: Miniaturized Rectangular Patch Antenna for UWB Applications

### 6.3.1 Design Specifications

| **Element** | **Dimensions(mm)** |
|---|---|
| Substrate Length | 26 |
| Substrate Width | 25 |
| Patch Length | 11 |
| Patch Width | 12.4 |
| Taper Width | 1.3 |
| Feed Width | 1.8 |
| Ground Plane Length | 11.65 |
| Ground Plane Width | 25 |

| | |
|---|---|
| Feed Length | 12.2 |

Table 6.1: Design Specifications of Proposed Antenna

## 6.4 Simulation Results

The above designed antenna is simulated using HFSS and the antenna parameters like Return Loss, VSWR, Radiation Pattern,etc., were observed.

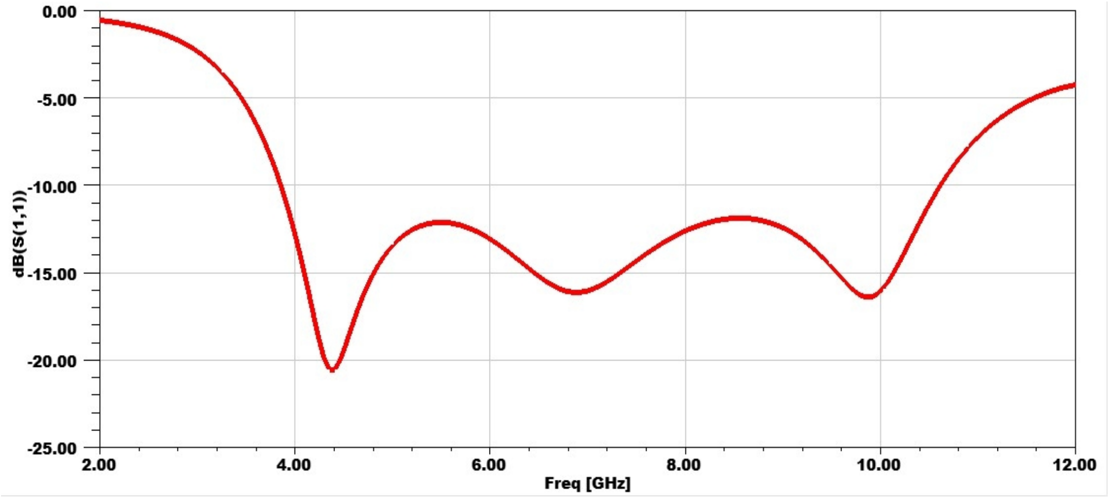


Fig.6.5: Return Loss for the proposed antenna

**Return loss** is the ratio of the reflected signal to the launched signal. That is, we want to have as less reflected signal as possible. This is because the more signal is reflected, this means we are delivering less signal to the load. Generally return loss of less than -10dB is preferred. From the fig.6.5 we can observe that the return loss is less than -10dB for the entire bandwidth i.e., from 3.86GHz to 10.61GHz.

**VSWR**(Voltage Standing Wave Ratio), is a measure of how efficiently radio-frequency power is transmitted from a power source, through a transmission line, into a load. The range of values for VSWR is from 1 to ∞. A **VSWR** value **under 2** is considered suitable for most antenna applications.We can observe from the fig.6.6, that for the entire bandwidth i.e., from 3.86GHz to 10.61GHz, the VSWR is less than 2.

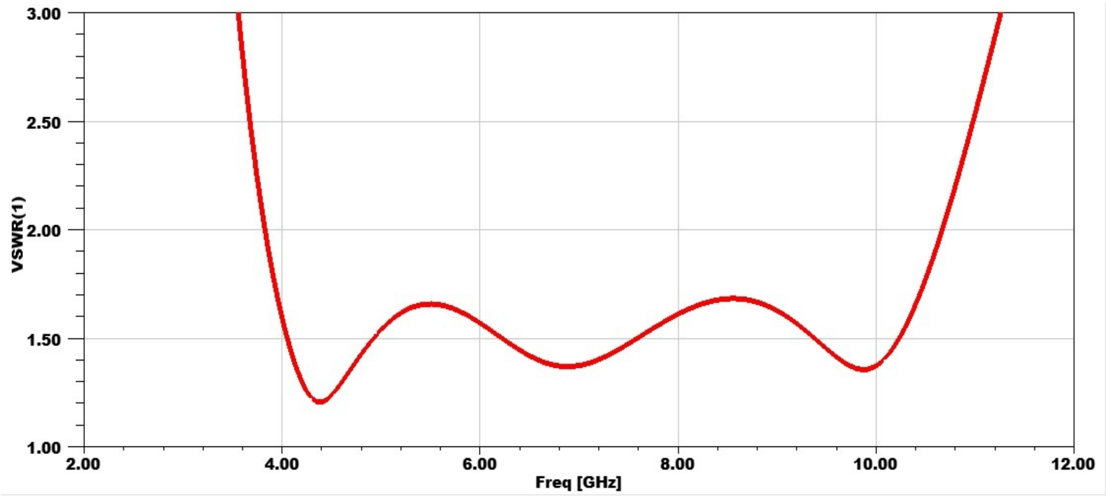


Fig.6.6:VSWR for the proposed antenna

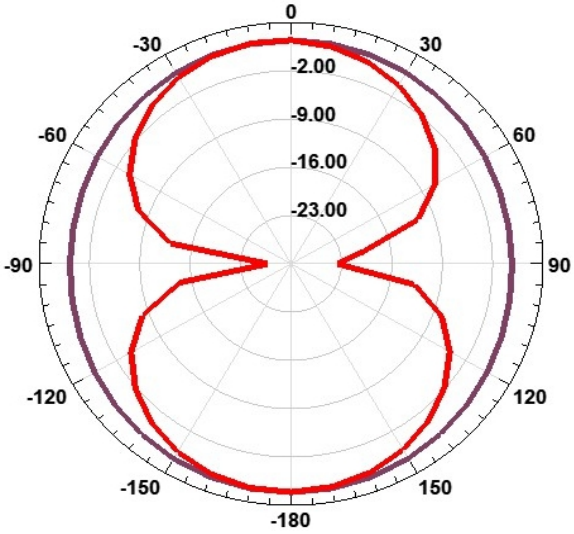


Fig.6.7: Radiation Pattern for the proposed antenna

The **radiation pattern** of an **antenna** is one of its basic properties since it shows the way the **antenna** distributes its energy in space. The gain of the antenna is measured by obtaining the radiation pattern for Phi=0° and Phi=90° at 5.8 GHz frequency was shown in Fig. The gain of the proposed antenna is 3dB.

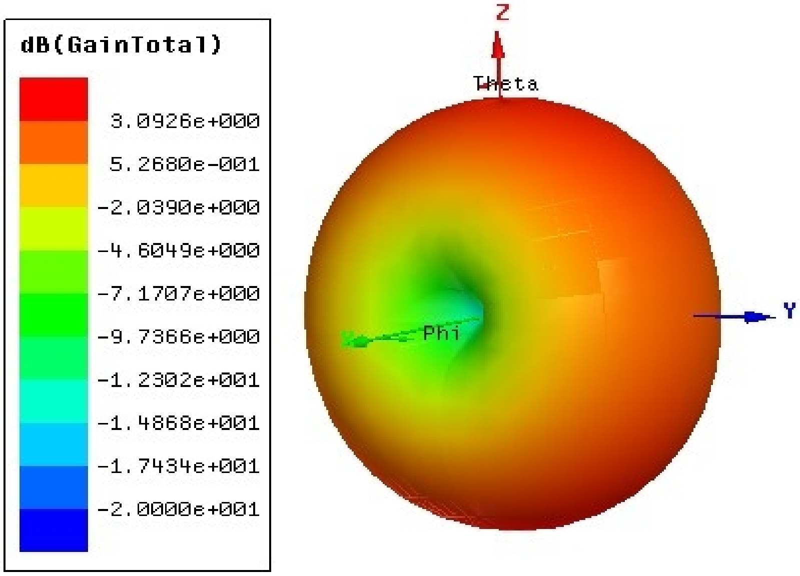


Fig.6.8: Gain in 3-D plot for the proposed antenna

# Conclusion

In the project, we have designed a miniaturized rectangular microstrip patch antenna that works in the UWB range i.e., from 3.86GHz to 10.61GHz. The proposed antenna has a simple geometry and design process. The antenna is miniaturized by 34.3% compared with the conventional patch antenna. The proposed antenna uses very low energy for short-range and high bandwidth communication for over a large portion of the radio spectrum. Various design parameters have been parameterized to achieve this type of microstrip patch antenna. By selecting the best results in the parametric sweep, with those parameter values, the best results were optimized.Various antenna parameters like Return loss, VSWR, Gain, Radiation pattern has been simulated and studied for the antenna. The return loss is below -10dB and VSWR are well below the mark (VSWR less than 2) for the operating frequency range of UWB.

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