MIMO ANTENNA FOR UWB APPLICATIONS WITH BAND NOTCH CHARACTERISTICS

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

BACHELOR OF TECHNOLOGY
IN
ELECTRONICS AND COMMUNICATION ENGINEERING

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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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CERTIFICATE

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ABSTRACT

Ultra-Wide Band Systems are gaining importance and are most suitable for wireless communications as they provide high data rates with high channel capacity and low power consumption. Various narrow band systems like WiMAX (3.4GHz - 3.69GHz), WLAN (5.15GHz - 5.825GHz), X-band Satellite Communication (7.25GHz - 8.4GHz) are also operating in the Ultra-Wide Band range which causes the interference of UWB systems with narrow band systems. Frequency band notching characteristics were introduced to avoid the interference. The proposed microstrip patch antenna is designed to operate in the UWB range with a narrow band rejection at WLAN frequency range of 5.15GHz - 5.825GHz by using a vertical stub protruding from the patch into feed. As wireless communication is prone to multipath fading and interference, MIMO (Multiple Input-Multiple Output) technology is combined with UWB technology. MIMO technology mitigates the multipath fading effect. A compact 34 x 34 x 1.6 mm^3 four element Ultra-Wide Band MIMO antenna with single band notch characteristics at 5.5GHz which is in WLAN (5.15GHz - 5.825GHz) range is designed by placing the symmetrical antenna elements orthogonal to each other in order to improve the isolation. The proposed antenna is operating in the frequency range of 2.6GHz - 12.6 GHz which covers the UWB range of 3.1GHz - 10.6GHz with a return loss below -10dB. MIMO diversity parameters like Envelope Correlation Coefficient (ECC), Diversity Gain (DG), Total Active Reflection Coefficient (TARC) and Mean Effective Gain (MEG) are under the acceptable practical values. The implemented design is simulated using High Frequency Structure Simulator (HFSS) software.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

An antenna is the interface between radio waves propagating through space and electric currents moving in metal conductors, used with a transmitter or receiver. In transmission, a radio transmitter supplies an electric current to the antenna's terminals, and the antenna radiates the energy from the current as electromagnetic waves (radio waves). In reception, an antenna intercepts some of the power of a radio wave in order to produce an electric current at its terminals that is applied to a receiver to be amplified. Antennas are essential components of all radio equipment.

1.2 ANTENNA BASICS

1.2.1 Definition of Antenna

There are several definitions of antenna. They are as follows:

- An Antenna is a device that converts electronic signals to electromagnetic waves and vice versa effectively with minimum loss of signals.
- An Antenna is a transducer that converts radio frequency (RF) fields into alternating current or vice versa. There are both receiving and transmission antennas for sending or receiving radio transmissions.

1.3 BASIC ANTENNA PARAMETERS

To describe the performance of antenna, definitions of various parameters are necessary. Some of the parameters are interrelated and not all of them need be specified for complete description of the antenna performance. Like for cellular mobile communication a circular polarized antenna is requires with high gain and for satellite communication in downlink a high directive antenna is required.

1.3.1 Radiation Pattern

The radiation pattern is defined as "a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. A radiation pattern defines the variation of power radiated by the antenna as a function of the direction away from the antenna. The power variation as a function of the arrival angle is observed in the antenna's far field. The radiation pattern is the graphical representation of radiation properties as a function of space.

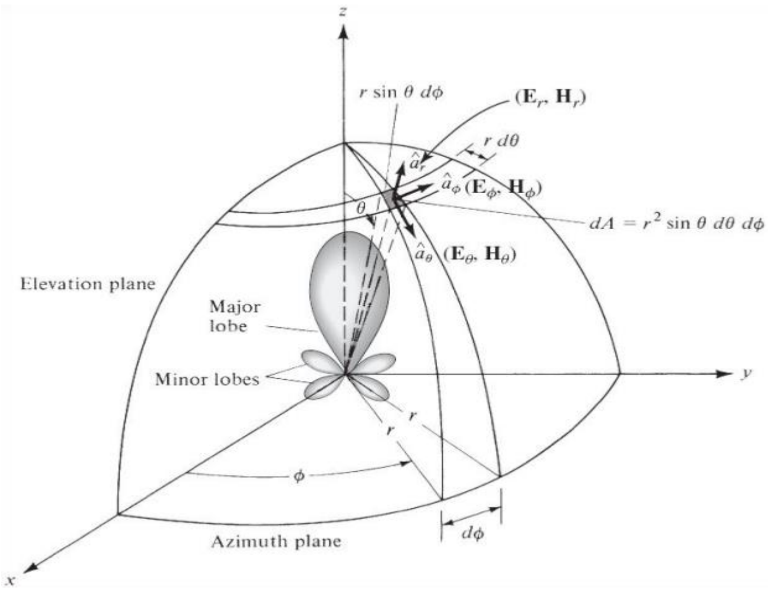


Fig. 1.1 Radiation Pattern in 3D-Plane of an antenna

1.3.2. Efficiency

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

General expression of the radiation efficiency is shown in (1.1).

$$\eta = \frac{P_{rad}}{P_{rec}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1.1)}$$

where, P_{rad} *is the* Power radiated by the antenna.

P_{rec} *is the* Power accepted by the antenna.

1.3.3. Radiation Intensity

Radiation Intensity in a given direction is defined as “the power radiated from an antenna per unit solid angle”. In mathematical form it is expressed in (1.2).

$$U = r^2 W_{rad} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1.2)}$$

where U = radiation intensity (W/unit solid angle)

W_{rad} = power radiation (W/m^2)

1.3.4. Directivity

Directivity of an antenna shows that how much the antenna is able to radiate in a particular given direction. The ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions is the directivity as shown in (1.3).

Directivity = maximum radiation intensity/average radiation intensity……… (1.3)

1.3.5 Return Loss

Return loss is a measure of the effectiveness of power delivery from a transmission line to a load such as an antenna. If the power incident on the antenna-under-test (AUT) is Pin and the power reflected back to the source is Pref, then the return loss can be defined as shown in (1.4).

$$\text{Return loss} = 10 \log_{10}(P_{in}/P_{ref}) \text{ dB} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1.4)$$

1.3.6 VSWR

VSWR describes how much energy is reflected from the antenna because of impedance mismatching. A perfectly impedance antenna would have VSWR equal to 1. VSWR than 2:1 (equivalent to a return loss of a -9.5 dB) 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. VSWR is given in (1.5).

$$\text{VSWR} = (1 + |\Gamma|)/ (1 - |\Gamma|) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1.5)$$

where, Γ is a voltage reflection coefficient at the input terminals of the antenna.

1.3.7 Gain

Antenna Gain is also referred as Power gain or Simply Gain. This combines of antenna efficiency and directivity. For transmitting antenna, it shows how efficiently antenna is stable to radiate the given power into space in a particular direction. While in case of receiving antenna shows how well the antenna is to convert the received electromagnetic waves into electrical power. When it is calculated with efficiency and directivity D it is referred as Power gain as given in (1.6).

$$\text{Power Gain} =| E_{antenna}| \text{ D} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (1.6)$$

1.3.8 Bandwidth

The bandwidth of an antenna expresses its ability to operate over a wide frequency range. It is often defined as the range over which the power gain is maintained to within 3dB of its maximum value, or the range over which the VSWR is no greater than 2:1, whichever is smaller. The bandwidth is usually given as a percentage of the nominal operating frequency. The radiation pattern of an antenna may change dramatically outside its specified operating bandwidth.

1.3.9 Effective Aperture

If the antenna is used to receive a wave with a power density S, it will produce a power in its terminating impedance of P_r watts. The constant of proportionality between P_r and S is Ae, the effective aperture of the antenna in square meters is given in (1.7).

$$P_r = \text{Ae S} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.7)$$

For some antennas, such as horn antennas or dish antennas, the aperture has an obvious physical interpretation, being almost the same as the physical area of the antenna, but the concept is just as valid for all antennas. The effective aperture may often be much larger than the physical area, especially in the case of wire antennas. Note however, that the effective aperture will reduce as the efficiency of the antenna decreases.

The antenna gain G is related to the effective aperture as shown in (1.8):

$$G = 4\pi/2\lambda A_e \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.8)$$

Where, Ae is the effective area of antenna, λ is the wave length of signal.

1.4 Types of Antennas

1.4.1 Log-Periodic Antenna

Fig 1.2: Log-Periodic Antenna

Another name for Log-Periodic Antennas is Log-Periodic Array. This antenna is a multi-element, directional narrow beam antenna. Which operates on a wide range of frequencies. This is made up of a series of dipoles placed along the antenna axis at different space intervals of time by the logarithmic function of the antenna frequency. These antennas are used in a wide range of applications, where variable bandwidth with antenna gain and directivity is required.

1.4.1.1 Bow-Tie Antennas

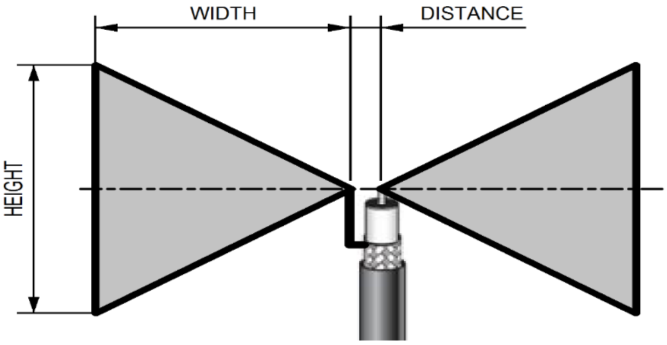


Fig 1.3: Bow-Tie Antenna

This type of antenna is also known as Biconical antenna or butterfly antenna. Biconical antennas are ubiquitous wide-band antennas. This antenna has a low-frequency response according to its size. And this acts as a high pass filter. As it reaches its upper limit, the radiation pattern of the antenna away from the design frequency becomes distorted and diffuses. Most bow tie antennas are biconical antenna derivatives. Discon is a type of semi-biconical antenna. A bow-tie antenna is a planar, and therefore, a directional antenna.

1.4.1.2 Log-Periodic Dipole Array

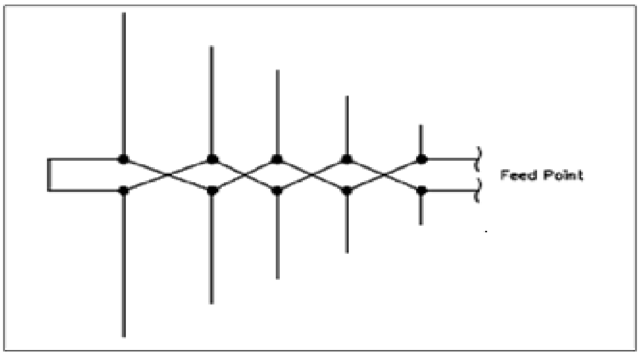


Fig 1.4: Log-Periodic Array

The most common type of antenna used in wireless communication technology is a log-periodical dipole array. Which basically consists of several bipolar elements. This bipolar array reduces the size of the antenna from the rear end to the front end. The main beam of this RF antenna comes from a small front end. The rear end element of the array is larger in size with half-wavelengths operating in the low-frequency range. The distance of the element decreases towards the front end of the array. Which includes small arrays. The frequency varies during this operation. A smooth transition occurs with an array of elements, leading to the formation of an active field.

1.4.2 Wire Antennas

This antenna is also known as a linear or curved antenna. These antennas are very easy to use, cheap, and are used in large quantities. These antennas are classified into different types as follows

The details of which are as follows.

- Short Dipole Antenna.
- Dipole Antenna.
- Monopole Antenna.
- Loop Antenna.

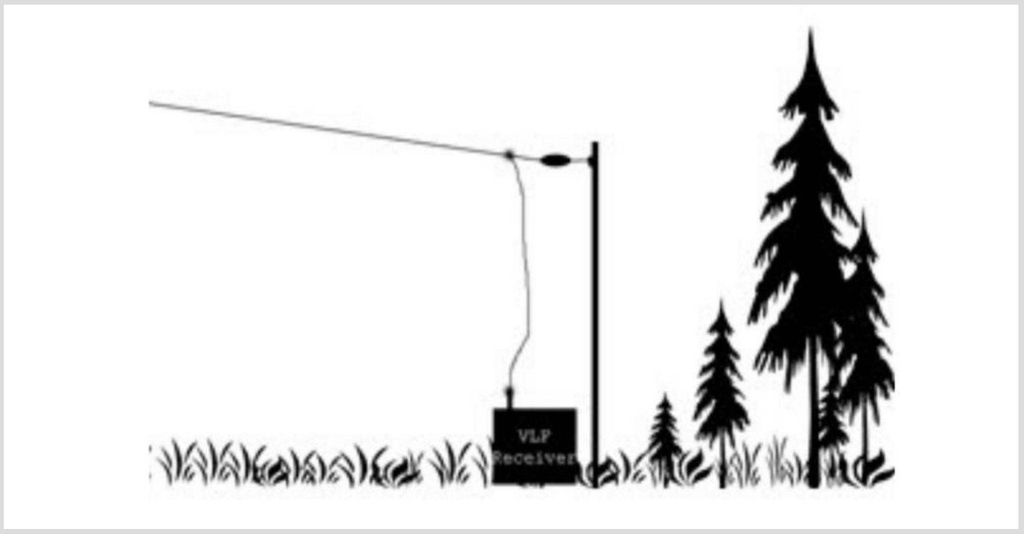


Fig 1.5: Wire antenna

1.4.2.1 Short Dipole Antenna

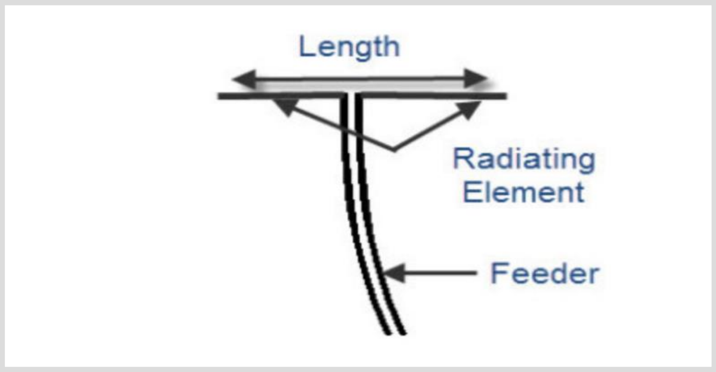


Fig 1.6: Short Dipole Antenna

This type of antenna is a simpler type of antenna than all types of antennas. This antenna has an open rotating wire. In which the short indicates “relative to the wavelength”. Therefore, this antenna prefers the size of the wire relative to the wavelength of the frequency of operation. It makes no consideration about the full size of the dipole antenna. The short dipole antenna is made up of two co-linear conductors. Which is a small distance between the conductor through the feeder. The dipole is considered short if the length of the radiating element is less than one-tenth of the wavelength.Short dipole antennas are made up of two co-linear conductors. Which is a small distance between the conductor through the feeder. Short dipole antennas are seldom satisfactory from a performance standpoint. This is because most of the power entering the antenna is depleted in the form of heat and the resistance loss is also gradually increasing.

1.4.2.2 Dipole Antenna

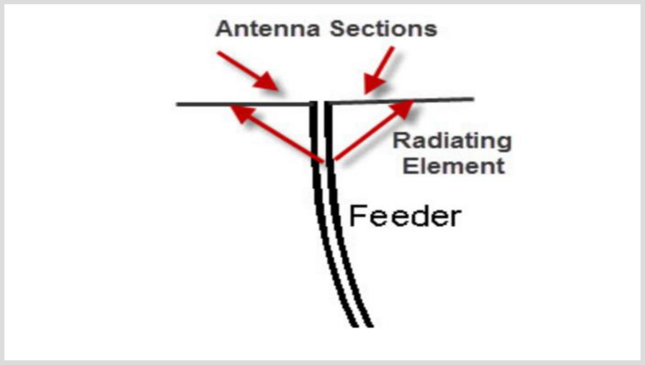


Fig 1.7: Dipole Antenna

Dipole antennas are one of the most straightforward antenna configurations. This Dipole antenna consists of two thin metal rods with a sinusoidal voltage difference between them. The lengths of rods are chosen in such a way that they have a quarter length of wavelength at operational frequencies. These antennas are used in the design of their own antennas or other antennas. It is very easy to build and use. Dipole Antenna has two metallic rods through which current and frequency flow. This current and voltage flow create an electromagnetic wave and the radio signals are red. The antenna contains a radiating element that splits the rods. And takes it from the receiver using the feeder on the transmitter. It creates currents through the centre. Different types of dipole antennas used as RF antennas include semi-wave, multiple, fold, non-resonant, and so on.

1.4.2.3. Monopole Antenna

A monopole antenna is half of a normal Dipole antenna located on a ground plane whose diagram is as follows.

Fig 1.8: Monopole Antenna

The radiation pattern above the ground plane will be similar to that of a half-wave dipole antenna. However, the total power developed is half that of a Dipole Antenna. This region extends only to the region of the upper hemisphere. The directivity of this antenna doubles compared to Dipole Antenna. These antennas are also used as vehicle mounting antennas. As they provide the ground plane required for the antennas on the ground.

1.4.2.4. Loop Antenna:

Loop Antenna shares a similar characteristic with both Dipole and Monopole antennas. As it is simple and easy to build. Loop Antenna is available in various shapes such as circular, elliptical, rectangular, etc. The basic characteristic of a loop antenna is independent of its shape. This is widely used in communication links with a frequency of about 3 GHz.

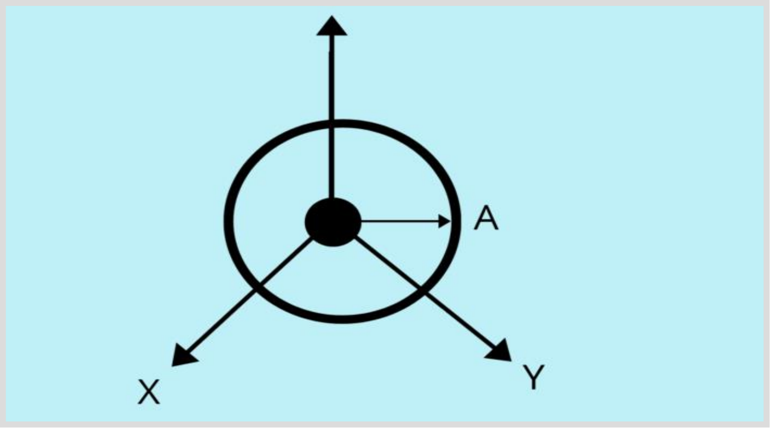


Fig 1.9: Loop Antenna

These antennas are also used as electromagnetic field probes in microwave bands. The circumference of the loop antenna determines the efficiency of the antenna. Dipole and monopole antennas are similar. These antennas are further classified into two types. Electrically small and electrically large depending on the circumference of the loop.

Electrically small loop antenna———> Circumference$\leq\lambda/10$

Electrically large loop antenna———> Circumference $\approx \lambda$

Single turn electrically small loops have smaller radiation resistance compared to their loss resistance. Smaller loop antennas can be improved by adding more turns to the radiation resistance. Multi-turn loops have higher radiation resistance, even if they have lower efficiency. Because of this small loop antennas are mostly used to receive antennas where loss is not mandatory. Small loops are not used to transmit antennas due to their low efficiency. Resonance loop antennas are larger in proportion. And is guided by the operation of the wavelength. They are also known as large loop antennas. Because they are used on higher frequencies such as VHF and UHF, in which their size is convenient. They can also be seen as fold-dipole antennas. And can be distorted into various shapes like round, square, etc. And have similar characteristics as high radiation efficiency.

1.4.3. Travelling Wave Antennas:

Travelling Wave Antennas are classified into different types which are discussed in detail below.

1.4.3.1. Helical Antennas:

Fig 1.10: Helical Antenna

Another name for helical antennas is helix antennas. It has a simple structure in the proportions of one, two, or more wires on each wound to form a helix. Usually supported by a ground plane or shaped reflector and run through the appropriate feed. The most common design of this is a wire that is supported by the ground and fed from a coaxial line.

The radiation properties of helical antennas, in general, are associated with this specification. The electrical size of the structure in which the input impedance is more sensitive to the pitch and the size of the wire.

Helical antennas have two main radiation modes: normal position and axial position. Axial mode is used in a wide range of applications. In normal conditions, the dimensions of the helix are smaller than its wavelength. These antennas act as short dipole or monopole antennas. In the axial position, the dimensions of the helix are the same as its wavelength. This antenna acts as a directional antenna. A helical antenna is an antenna consisting of one or more conducting wires wound in the form of a helix.

1.4.3.2. Yagi-Uda Antennas:

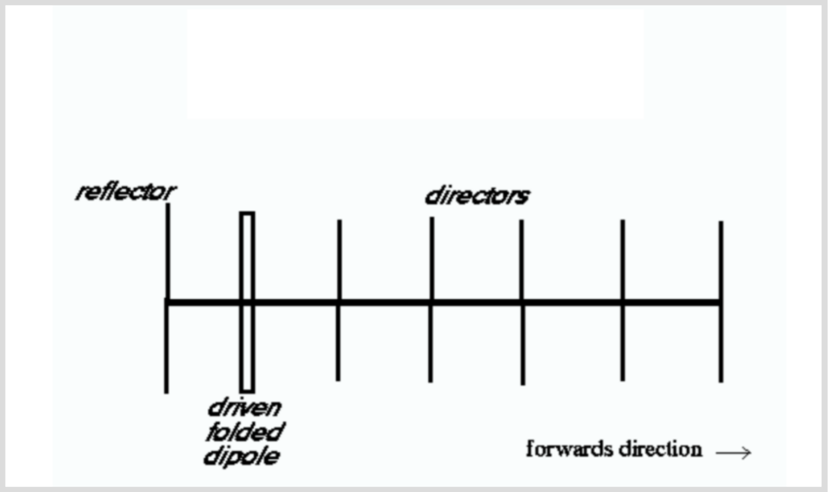


Fig 1.11: Yagi-Uda Antenna

Another antenna that uses passive elements is the Yagi-Uda antenna. This type of antenna is affordable and effective. It can be made up of one or more reflective elements and one more directing element.

The Yagi antenna can be mounted for horizontal polarization in the forward direction using an antenna with a reflector-driven fold-dipole active element and directors.

1.4.4. Microwave Antennas:

Microwave Antennas to Antennas Working on Microwave Frequencies Known as. These antennas are used in a wide range of applications.

1.4.4.1. Rectangular Microstrip Antennas:

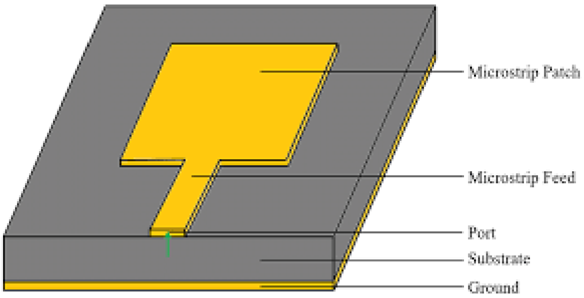


Fig 1.12: Rectangular Microstrip Antenna

Low-profile antennas are selected for spacecraft or aircraft applications based on specifications such as size, weight, cost, operation, ease of installation, etc. Such antennas are known as rectangular microstrip antennas or patch antennas. They just need space for the feed line. Which is usually placed behind the ground plane. The disadvantage of such antennas is that they are inefficient and have very narrow bandwidth. Which is usually a fraction of a percent or a few percent at most.

1.4.4.2. Planar Inverted-F Antennas:

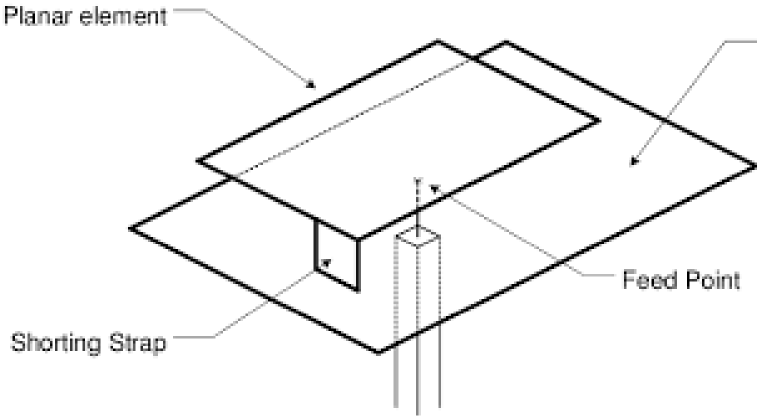


Fig 1.13: Planar Inverted-F Antenna

Planar Inverted-F Antennas can be considered as a type of linear inverted F antenna (IFA). In which the wire radiating element is replaced by a plate to increase the bandwidth. The advantage of such antennas is that they can be hidden in the housing of the mobile when compared to different types of antennas such as whip, rod or helical antenna, etc.

Another advantage of these antennas is that they absorb power and reduce the back rays from the top of the antenna, which increases efficiency. Its high advantage in both horizontal and vertical positions. This feature remains the most important for any type of antenna used in wireless communication.

1.4.5. Reflector Antennas:

An antenna reflector is a device that reflects electromagnetic waves. Antenna reflectors can act as standalone device for redirecting radiofrequency energy, or can be integrated as a part of antenna array.

Reflector Antennas are classified into two types which are further discussed below.

1.4.5.1. Corner Reflector Antenna:

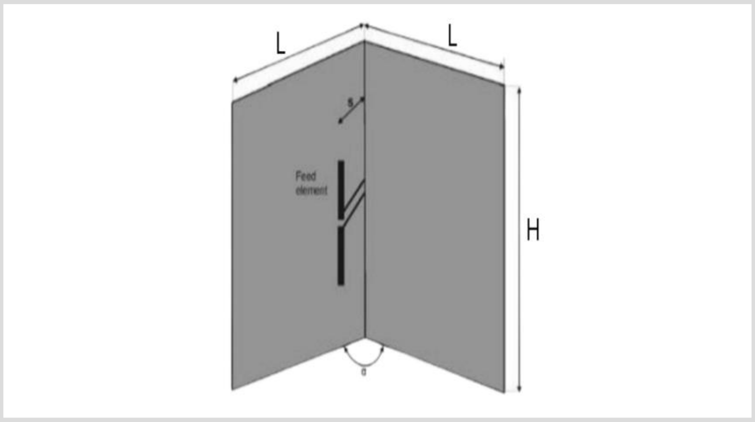


Fig 1.14: Corner Reflector Antenna

An antenna that consists of one or more dipole elements placed in front of an angled reflector. That one angle is known as Corner Reflector Antenna. The direction of the antenna can be increased by using this reflector. In the case of a wire antenna, a conducting sheet is used behind the antenna to direct the radiation forward.

1.4.5.2. Parabolic-Reflector Antenna:

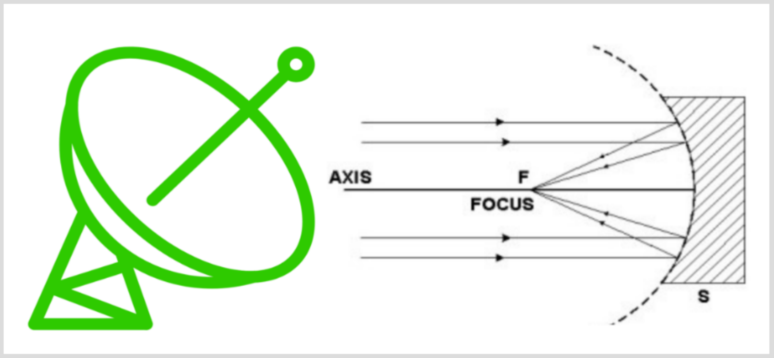


Fig 1.15: Parabolic Reflector Antenna

The radiating surface of a parabolic antenna has a much larger dimension than its wavelength. Geometric optics based on rays and wavefront are used to find out some of the features of this antenna. Some of the important properties of these antennas can be applied using ray optics and other antennas using electromagnetic field theory.

CHAPTER 2

MICROSTRIP PATCH ANTENNA

2.1 INTRODUCTION

An antenna that is formed by etching out a patch of conductive material on a dielectric surface is known as a patch antenna. The dielectric material is mounted on a ground plane, where the ground plane supports the whole structure. Also, the excitation to the antenna is provided using feed lines connected through the patch. As it is formed using a microstrip technique by fabricating on a printed circuit board this is also known as Microstrip antenna or printed antenna.

The Microstrip Patch Antenna is a single-layer design which consists generally of four parts (patch, ground plane, substrate, and the feeding part). A Microstrip Antenna in its simplest form consists of a radiating patch on one side of Dielectric substrate and a ground plane on the other side. Most common shapes are rectangular and circular. However, other Shapes such as the square, meandered, triangular, semi-circular and annular ring Shapes are also used. Some of the shapes are shown in the below figure. The most commonly used types are rectangular and circular patch antennas. The patch is a very thin ($t \ll \lambda_0$, where λ_0 is the free space wavelength) radiating metal strip (or array of strips) located on one side of a thin non conducting substrate, the ground plane is the same metal located on the other side of the substrate. The metallic patch is normally made of thin copper foil plated with a corrosion resistant metal, such as gold, tin, or nickel. Substrate is a base or container on which a microstrip patch (metallic sheet) antenna is fabricated and it plays an important role in microstrip antenna functioning. The substrate layer thickness is 0.01–0.05 of free-space wavelength. The substrate in microstrip antennas is principally needed for the mechanical support of the antenna. To provide this support, the substrate should consist of a dielectric material, which may affect the electrical performance of the antenna, circuits and transmission line.

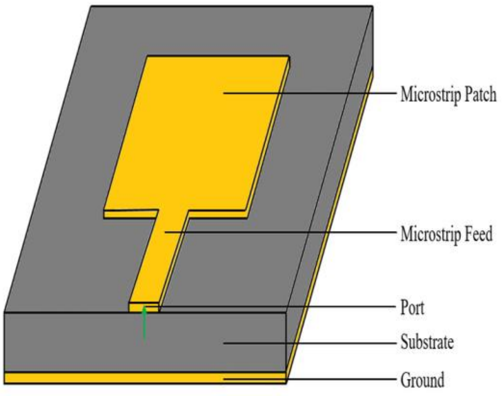
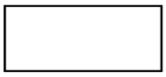


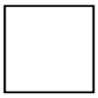
Fig 2.1: Structure of Microstrip Patch Antenna

2.2 Types of Patch Antennas

In its simplest form a microstrip patch antenna consists of a patch of metal, generally rectangular or circular in shape. The commonly available shapes of patch antenna are rectangular, circular, dipole, triangular, square and elliptical with rectangular and circular shapes the most common among them. The various shapes are shown in the below figure.

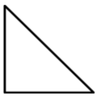


(a) Rectangular

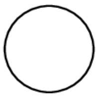


(b) Square

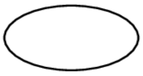
(c) Dipole



(d) Triangular



(e) Circular



(f) Elliptical

With changing the substrate material, the dielectric constant of the substrate changes i.e., changing the substrate material means changing the dielectric constant (εr). The performance parameters such as gain, directivity and bandwidth are changed with dielectric constant.

2.3 Design Equations

For designing a microstrip patch antenna, select the resonant frequency and a dielectric medium for which the antenna is to be designed. The parameters to be calculated are as shown below.

1. Width(W): The width of the patch is calculated using the following equation 2.1

$$W = \frac{C}{2f}\sqrt{\frac{2}{\in_r+1}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.1)}$$

where, W=Width of the patch

C = Speed of light

$\in_r$ = Dielectric constant of the substrate

f = resonant frequency

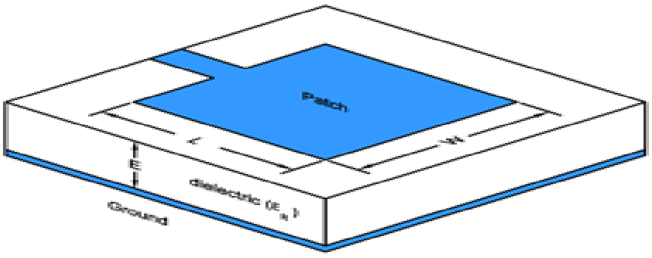


Fig 2.2: Structure of Microstrip Patch Antenna with dimensions

2.**Effective Refractive Index ($\in_{reff}$):** The effective refractive index value of a patch is an important parameter in the designing procedure of a microstrip patch antenna. The radiations traveling from the patch towards the ground pass through air and some through the substrate (called as fringing). Bath the air and the substrates have different dielectric values, therefore in order to account for this we find the value of effective dielectric constant.

$$\in_{reff} = \left(\frac{\in_r+1}{2}\right) + \left(\frac{\in_r-1}{2}\right)\left(1+\frac{12h}{w}\right)^{\frac{-1}{2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (2.2)$$

Where $\in_{reff}$ is the effective dielectric constant, $\in_r$ is the dielectric constant of substrate, h is the thickness of dielectric substrate, *w* is the width of the patch.

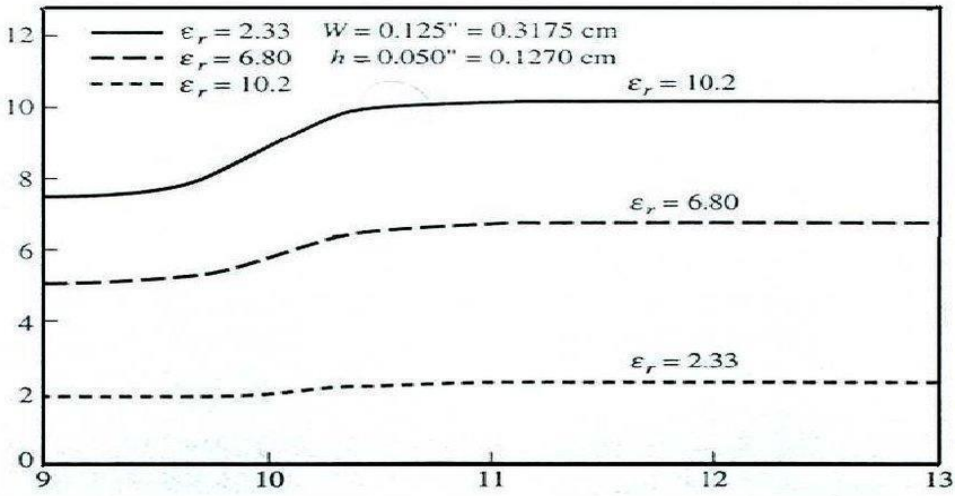


Fig 2.3: Effective dielectric constant versus substrate for typical substrates

3.**Length (L):** Due to fringing, electrically the size of the antenna is increased by an amount of (ΔL). Therefore, the actual increase in length (ΔL) of the patch is to be calculated using the following equation (2.3 – 2.5).

$$L_{eff} = \frac{c}{2f\sqrt{\in_{reff}}} = \mathrm{L}+2\Delta L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

$$L = \frac{C}{2f\sqrt{\epsilon_r}} \dots\dots\dots \quad (2.4)$$

$$\Delta L = 0.412\frac{(\epsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \dots\dots\dots \quad (2.5)$$

Where L_{eff} is the effective length of patch, w is the width of the patch, h is the thickness of the substrate, f is the resonant frequency, C is the speed of light in free space.

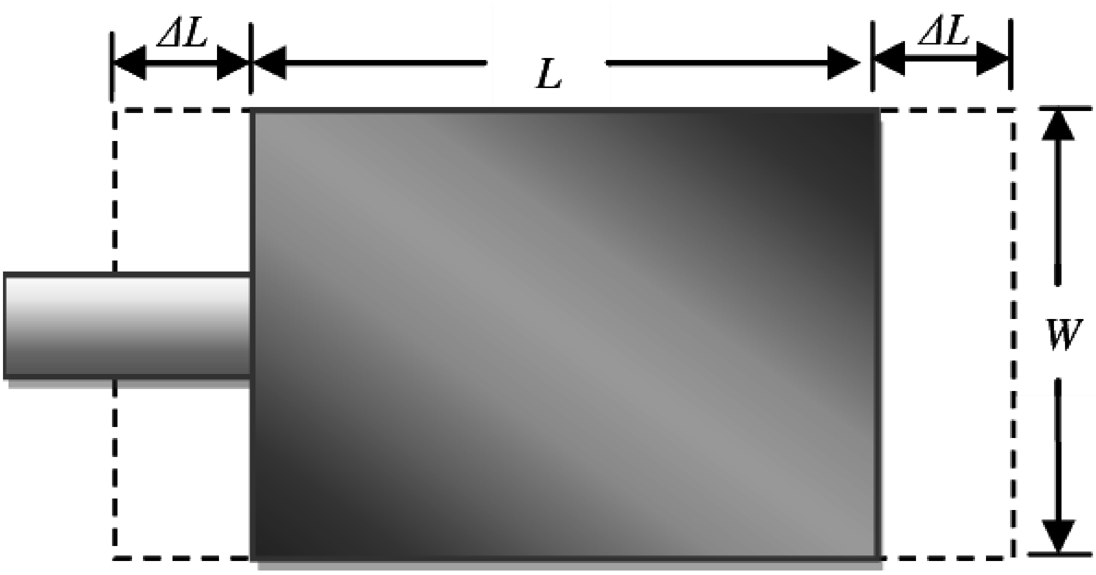


Fig 2.4: Physical length and effective length of microstrip patch antenna

4.Length (L_s) and width (W_s) of substrate: Now the dimensions of a patch are known. The length and width of a substrate is equal to that of the ground plane. The length of a substrate (L_s) and the width of a substrate (W_s) are calculated using the following equations 2.6 and 2.7

$$L_s = L_p + 6h \dots\dots \quad (2.6)$$

$$W_s = W_p + 6h \dots\dots \quad (2.7)$$

2.4 Feeding Techniques

There are several methods for feeding the signal into microstrip patch antennas. Let the conducting patch be a rectangular one which exists on one side of the dielectric substrate. Let `L' represents length and `W' represents width of a rectangular conducting patch. The microstrip substrate has dielectric constant, denoted by εr and thickness, h. The antenna feed can be either contacting type in which the RF signal is directly fed through the contacting element like coaxial cable, or it may be non-contacting type in which the RF signal is transferred through electromagnetic coupling. There are a lot of techniques of feeding the RF signal into a microstrip patch antenna but four techniques are very popular. They are

1. Microstrip line
2. Coaxial probe
3. Proximity coupling
4. Aperture coupling

2.4.1 Microstrip Line Feed

It is a conducting strip having width extremely smaller than the width of the radiating element. Due to thinner dimensions of the strip, the feed line offers easy etching on the substrate. The feed line to the structure can be provided either at the centre, inset or offset.

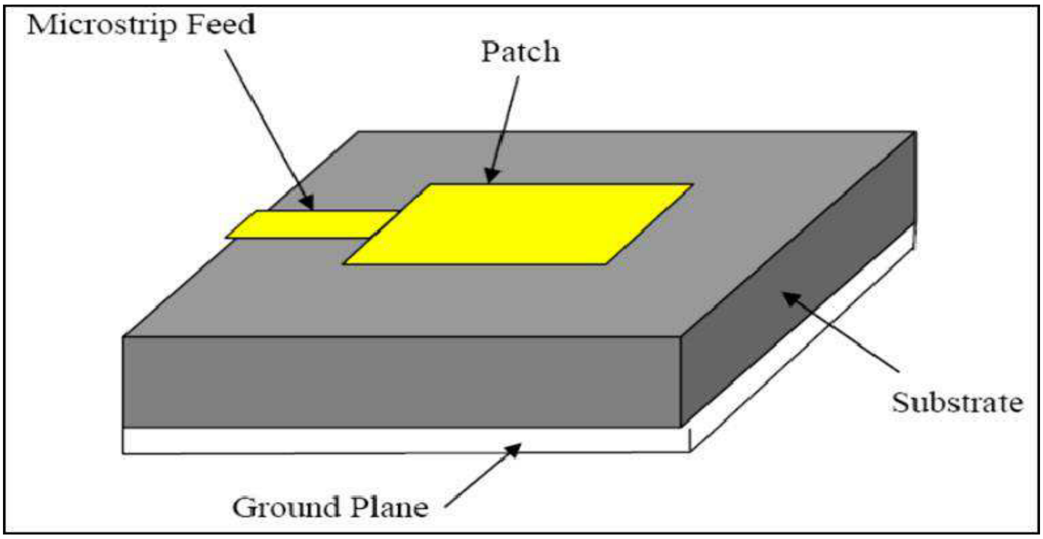


Fig 2.5: Microstrip line Feed

This method of feeding is very widely used because it is very simple to design and analyse, and very easy to manufacture. The purpose of the inset cut in the patch is to match the feed line's impedance to the patch without the need for any additional matching element.

2.4.2 Coaxial cable

The co-axial feed is a non-planar feeding technique in which z coaxial cable is used to feed the patch. The inner conductor of the coaxial connector extends through the dielectric, making a metal contact with the patch, and the outer conductor of the cable is connected to the ground plane, as shown in figure.

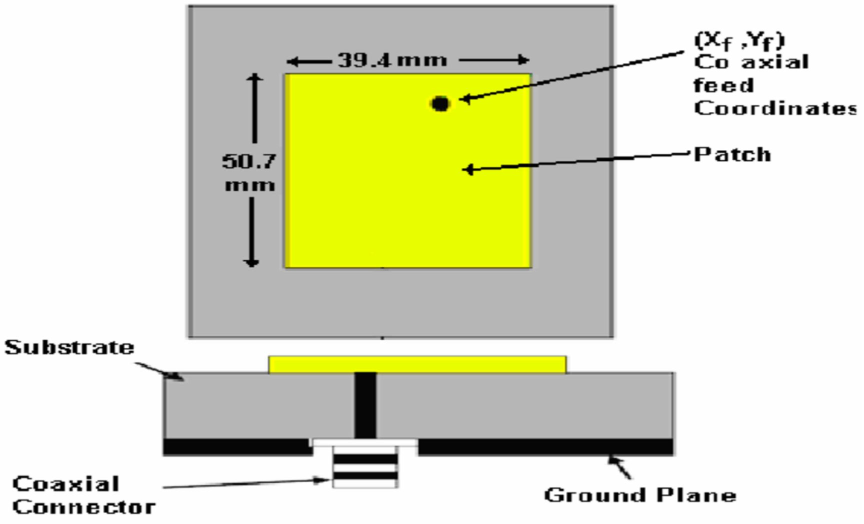


Fig 2.6: Coaxial Cable

With the variation in the position of the coaxial feed, the impedance also varies. As the feed line can be connected anywhere within the patch thus facilitates impedance matching. However, connecting the feed line with the ground plane is a bit difficult as this will require drilling a hole in the substrate.

2.4.3 Proximity Coupling

In proximity feed, the feed line is placed between two dielectric substrates. In the edge fed technique, it is impossible to choose a 50 ohms feed point since the impedance at the edges will be very high. To overcome this, the feed line is moved to a lower level below the patch. The edge of the feed line is located at a point where the antenna input impedance is 50 ohms. Here the power transfer from the feed to the patch takes place through electromagnetic field coupling. Since the feed line has been moved to a lower level, feed line radiation has been reduced to a great extent, and also, this technique allows planar feeding

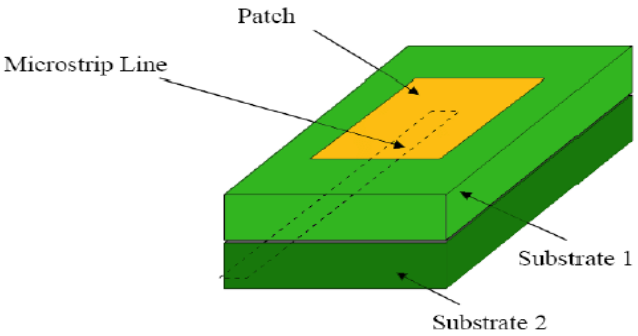


Fig 2.7: Proximity Coupling

2.4.4 Aperture coupling

The aperture feed technique consists of two dielectric substrates, namely antenna dielectric substrate, and feed dielectric substrate. These dielectric substrates are separated by a ground plane, which has a slot at its centre. The metal patch is placed on top of the antenna substrate is shown in

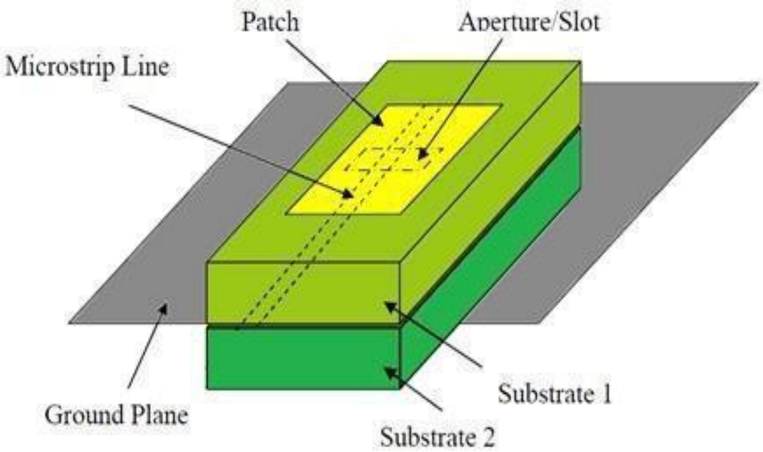


Fig 2.8: Aperture Coupling

2.5 Advantages and disadvantages

There are various advantages and disadvantages of microstrip patch antennas. Some of them are given below.

2.5.1 Advantages of microstrip patch antennas

1. The antenna is of small size and less bulky.
2. It offers an easy fabrication process.
3. Due to less volume and small size, there is an easy installation.
4. It provides easy integration with other devices.
5. It can perform dual and triple frequency operations.
6. The arrays of the antenna can be easily constructed.
7. It offers a high degree of robustness over rigid surfaces.

2.5.2 Disadvantages of microstrip patch antennas

1. The antenna efficiency is low.
2. These antennas show highly sensitive behaviour towards environmental factors.

3. These exhibit low power handling ability, low gain, and narrow bandwidth.

4. These are more prone to spurious feed radiation.

5. There are more dielectric and conductor losses in microstrip antennas.

2.6 Applications of microstrip patch antennas

1. The low-profile structure of microstrip antennas offers its wide use in wireless communications. This is the reason these antennas show compatibility towards handheld devices like pagers and mobile phones.

2. Due to the thin structure of these antennas, these are used as communication antennas on missiles.

3. Satellite communication and microwave applications also make use of microstrip antenna due to its small size.

4. GPS i.e., Global Positioning System is one of the major advantages of microstrip antennas. As it offers ease in tracking vehicles and marines.

5. These antennas also find applications in phased array radars that can handle bandwidth tolerance up to some percentage.

CHAPTER 3

UWB ANTENNA DESIGN AND RESULTS

3.1 UWB ANTENNA

Ultra-Wide Band is a fast, secure and low power radio protocol used to determine location with accuracy unmatched by any other wireless technology. UWB antennas are gaining prominence and becoming very attractive in modern and future wireless communication systems, mainly due to two factors. Firstly, people increasingly high demand for the wireless transmission rate and UWB properties such as high data rate, low power consumption and low cost. Secondly, now the wireless portable device need antenna operated in different frequencies for various wireless transmission functions, and operation bans and functions are increasing more and more. The bandwidth is the antenna operating frequency band within which the antenna performances, such as input impedance, radiation pattern, gain, efficiency, and etc., are desired. The most commonly used definitions for the antenna bandwidth are the fractional bandwidth (for narrow or wideband definition) and the bandwidth ratio (for ultra-wideband definition).

3.2 UWB DEFINITION

Ultra-wideband 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.

3.3 ADVANTAGES OF UWB ANTENNAS

- **Ability to Share the Frequency Spectrum** – The FCC's power requirement of –41.3 dBm/MHz, equal to 75 nanowatts/MHz for UWB systems, puts them in the category of unintentional radiators, such as TVs and computer monitors. However, this all depends on the type of modulation used for data transfer in a UWB system.

- **Large Channel Capacity** - One of the major advantages of the large bandwidth for UWB pulses is improved channel capacity. Channel capacity, or data rate, is defined as the maximum amount of data that can be transmitted per second over a communications channel.
- **Low probability of Intercept and Detection** - Because of their low average transmission power, as discussed in previous sections, UWB communications systems have an inherent immunity to detection and intercept. With such low transmission power, the eavesdropper has to be very close to the transmitter (about 1 meter) to be able to detect the transmitted information.

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

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

3.4 DISADVANTAGES OF UWB ANTENNAS

- Slower adoption rate
- Higher cost
- Long signal acquisition times
- FCC has limited emission requirements which is less than 0.5mWatt max power over 7.5 GHz band
- The UWB technology has issues of co-existence and interference with other radio-based technologies

3.5 UWB ANTENNA DESIGN AND RESULTS

3.5.1 Basic Square Patch Antenna

A basic square patch antenna designed using FR4 substrate with a dielectric constant of 4.4, thickness of 1.6mm and a loss tangent of 0.02 is shown in fig 3.1. The antenna is designed to resonant at a frequency of 6.3GHz by using equations (2.1 – 2.7).

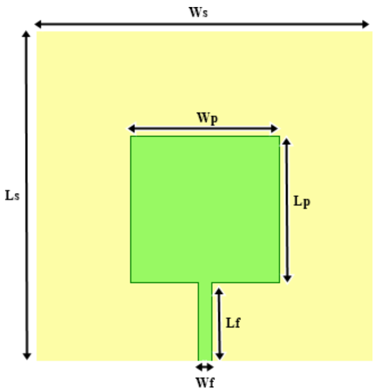


Fig 3.1: Basic Square Patch Antenna

The dimensions of the basic square patch antenna shown in table 3.1

Table 3.1: Dimensions of a basic square patch antenna

PARAMETER	VALUE (in mm)
Length of the Feed (L_f)	5.7
Width of the Feed (W_f)	1
Length of the Patch (L_p)	10.5
Width of the Patch (W_p)	10.5
Length of the substrate (L_s)	24
Width of the substrate (W_s)	24

The square patch antenna is designed to have S_{11} < -10dB and VSWR < 2 at the resonant frequency. Return loss and VSWR are shown in fig 3.2 and 3.3 respectively.

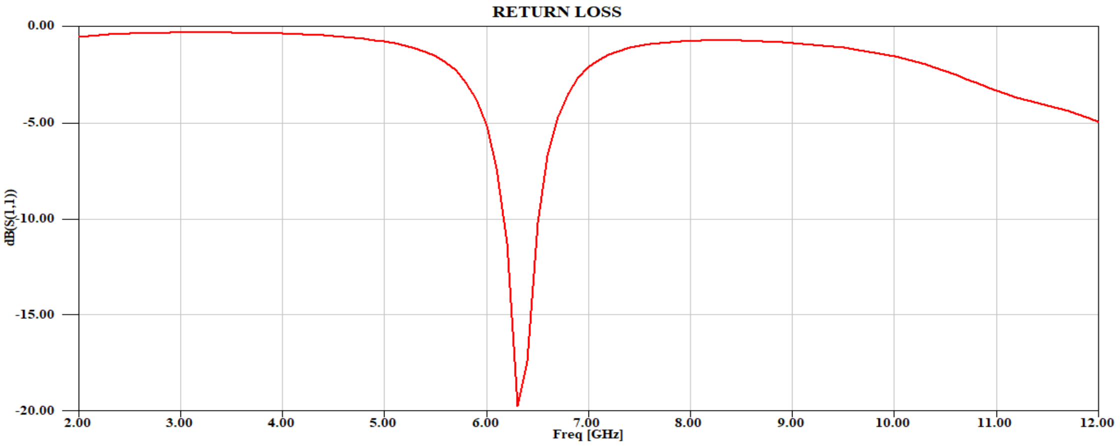


Fig 3.2: Return loss of basic square patch antenna

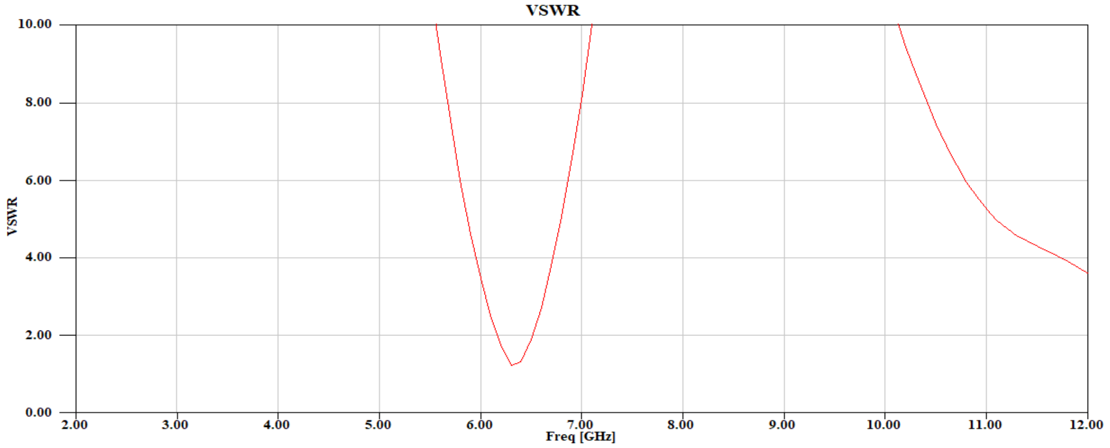


Fig 3.3: VSWR of basic square patch antenna

S_{11} is the reflection coefficient which is the ratio of reflected power to incident power at port1. S_{11} expressed in dB gives the return loss. S_{11}(dB) should be less than -10dB which indicates that at least 90% of incident power is being absorbed and only 10% of incident power is being reflected.

Voltage Standing Wave Ratio (VSWR) is another important parameter which is the ratio of maximum to minimum voltage on a lossless line.

The parameters S_{11} and VSWR are a measure of how efficiently RF power is transmitted from the power source, through a transmission line and into the load.

From the simulated return loss shown in fig 3.2, return loss is less than -10dB in the frequency range of 6.16GHz - 6.5GHz and minimum S_{11} of -19.7dB is obtained at the resonant frequency 6.3GHz which is the acceptable value.

From the simulated VSWR shown in fig 3.3, VSWR is less than 2 at the resonant frequency 6.3GHz which is the acceptable value.

3.5.2 Ultra-Wide Band Antenna

An ultra-wide band antenna is designed to operate in the frequency range of 2.8GHz - 12.3GHz which covers the ultra-wide band range of 3.1GHz - 10.6GHz is shown in fig 3.4.

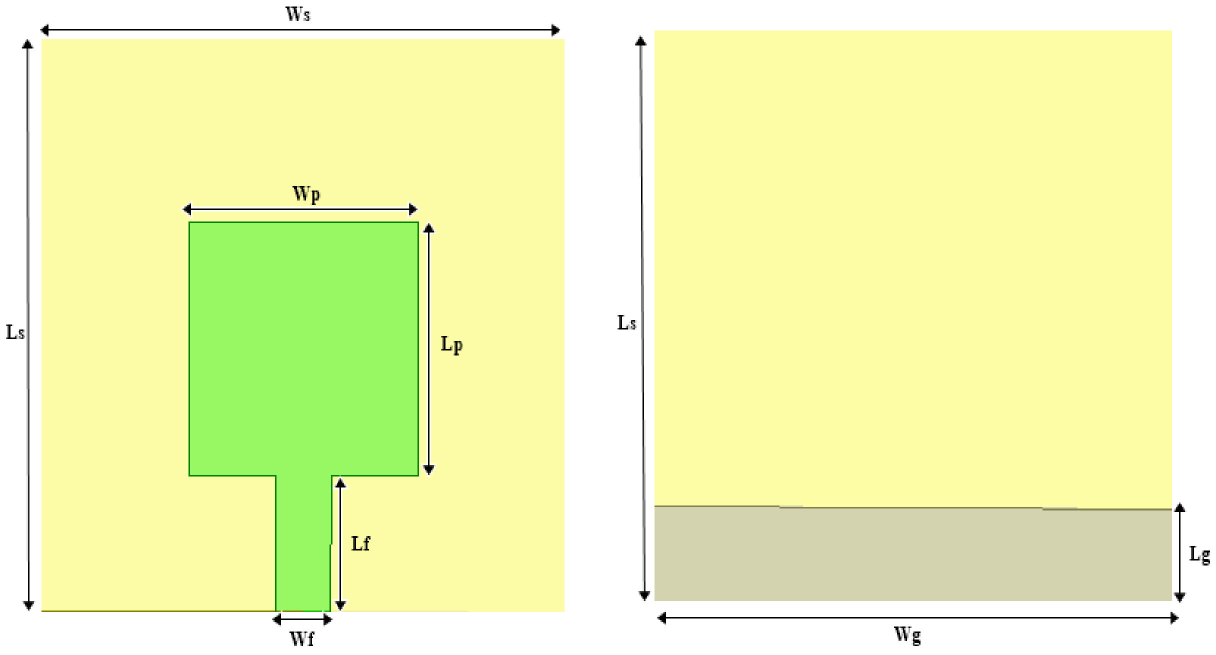


Fig 3.4: Ultra-Wide Band Antenna

The dimensions of the ultra-wide band antenna are mentioned in below table 3.2.

Table 3.2: Dimensions of Ultra-Wide Band Antenna

PARAMETERS	**VALUE (in mm)**
Length of the substrate (L_s)	24
Width of the substrate (W_s)	24
Length of the Patch (L_p)	10.5
Width of the Patch (W_p)	10.5
Length of the Feed (L_f)	5.7
Width of the Feed (L_f)	2.5
Length of the Ground (L_g)	4
Width of the Ground (W_g)	24

The ultra-wide band antenna is designed by using a partial ground and by increasing the width of the feed line. Partial ground reduces the energy stored in the substrate. As the stored energy reduces Q-factor decreases which in turn increases the bandwidth. Q-factor and bandwidth are inversely proportional as shown in equation 1.

$$Q = \frac{f_r}{BW} \text{ ....} (3.1)$$

Where f_r is the resonant frequency, Q is the quality factor and BW is the operating bandwidth. A parametric analysis is carried out to find the ground length by varying ground length from 4mm to 4.8mm in steps of 0.2mm. The parametric analysis results are shown in fig 3.5.

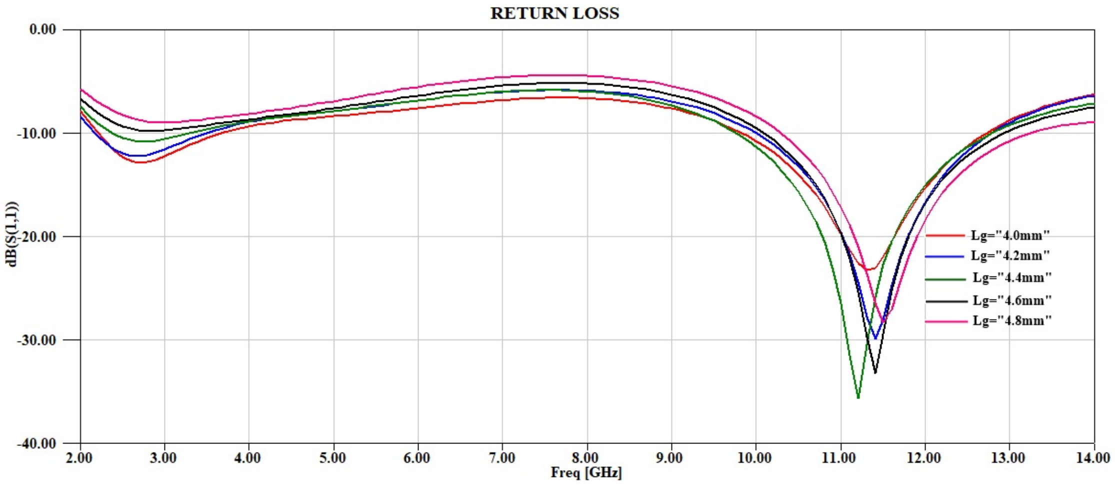


Fig 3.5: partial ground length parametric analysis results

From the parametric analysis results shown in fig 3.5, return loss is > -10dB but minimum return loss is obtained when ground length is 4mm.

Hence by taking ground length as 4mm feed width is varied from 1mm to 3mm in steps of 0.5mm. Changing the feed width changes the impedance matching bandwidth. The parametric analysis results are shown in fig 3.6.

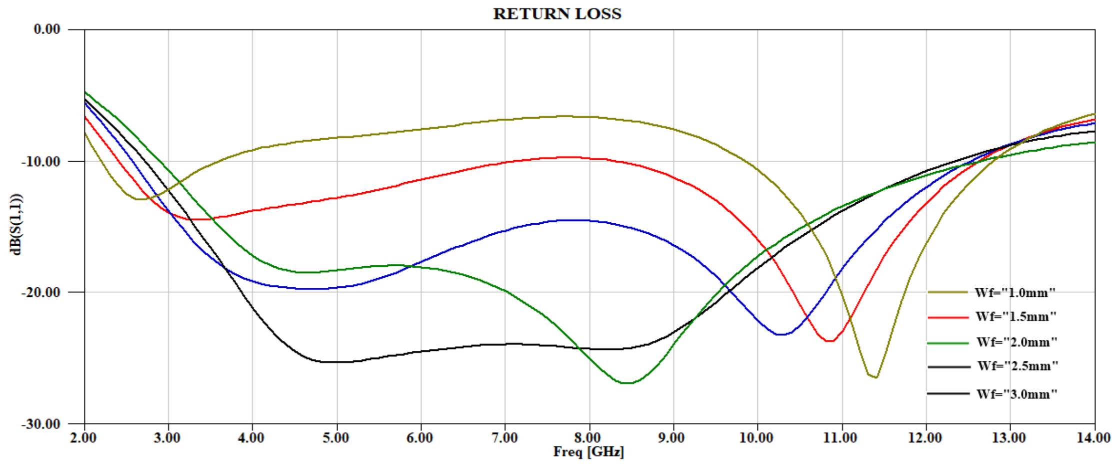


Fig 3.6: Feed width Parametric analysis results

From the feed width parametric analysis results shown in fig 3.6, better UWB response is obtained when the feed width is 2.5mm. Then the feed width is varied from 2.0mm to 2.5mm in steps of 0.5mm and ground length is varied from 3.8mm to 4.2mm in steps of 0.2mm at the same time and the simulated results are shown in fig 3.7.

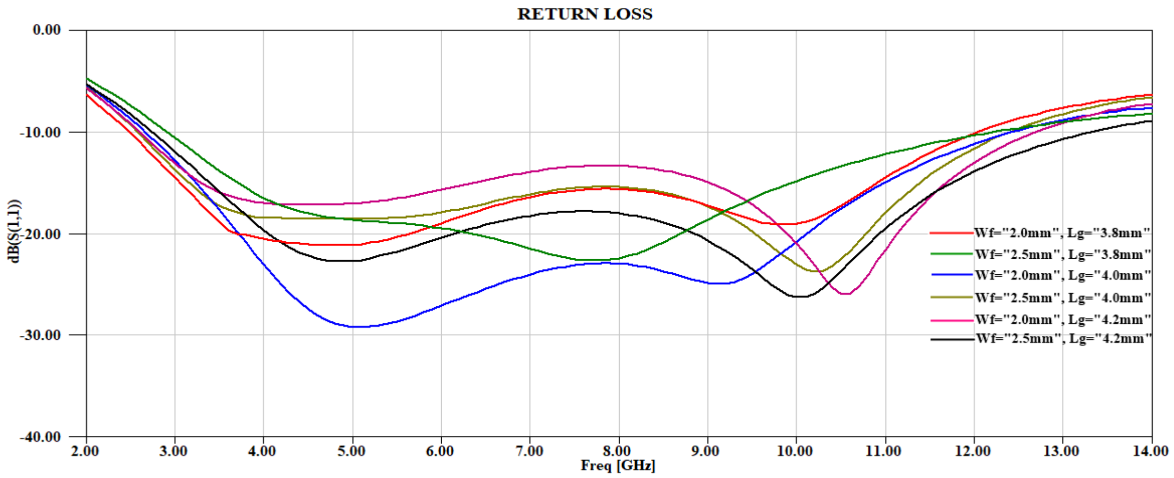


Fig 3.6: Feed width and ground length Parametric analysis results

From the feed width and ground length parametric analysis results shown in fig 3.7, better UWB response is obtained when ground length is 4mm and feed width is 2.5mm. Return loss and VSWR of UWB antenna are shown in fig 3.8 and 3.9 respectively.

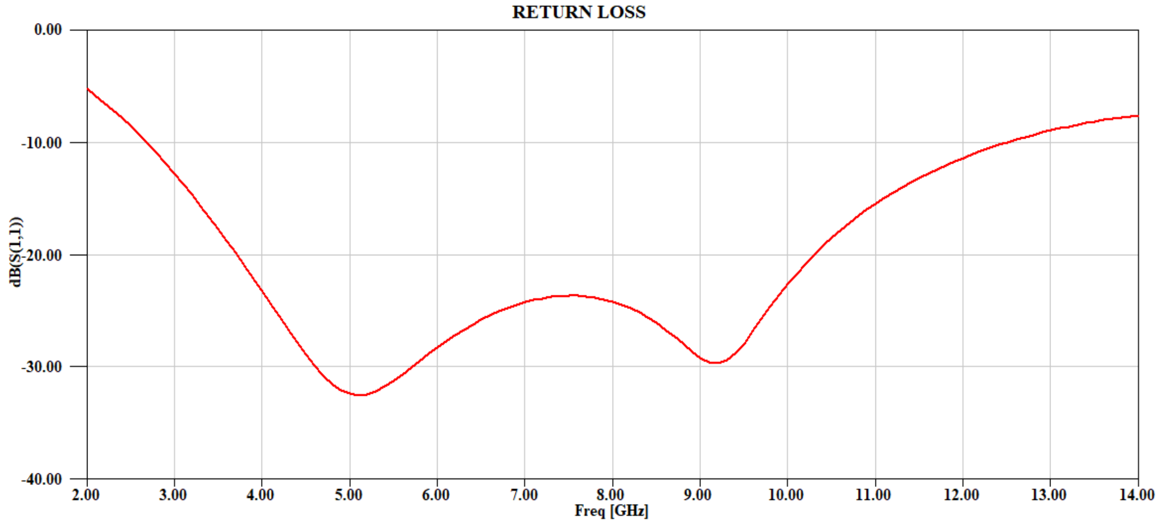


Fig 3.8: Return Loss of UWB Antenna

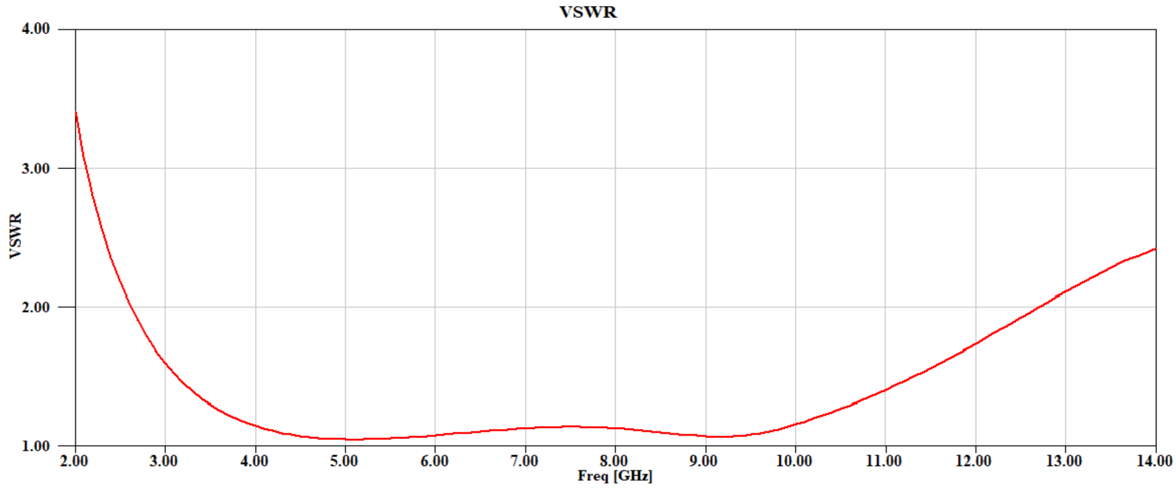


Fig 3.9: VSWR of UWB Antenna

From the simulated return loss shown in fig 3.8, antenna is operating in the frequency range 2.8GHz - 12.3GHz as the return loss is < -10dB in the entire range and a minimum return loss of -32dB is obtained at 5.1GHz. From the simulated VSWR shown in fig 3.9, VSWR of antenna is less than 2 in the entire frequency range which is the acceptable value. Three-dimensional gain and two-dimensional radiation pattern of antenna are shown in fig 3.10 and 3.11 respectively.

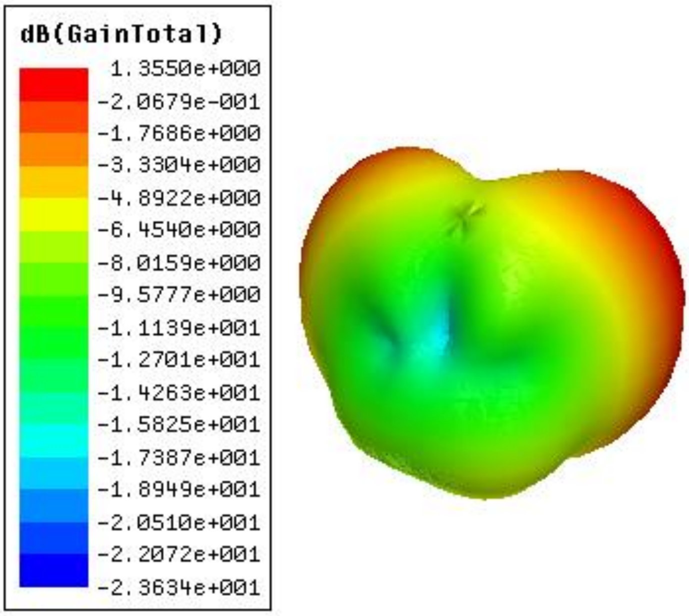


Fig 3.10: Gain plot of UWB antenna

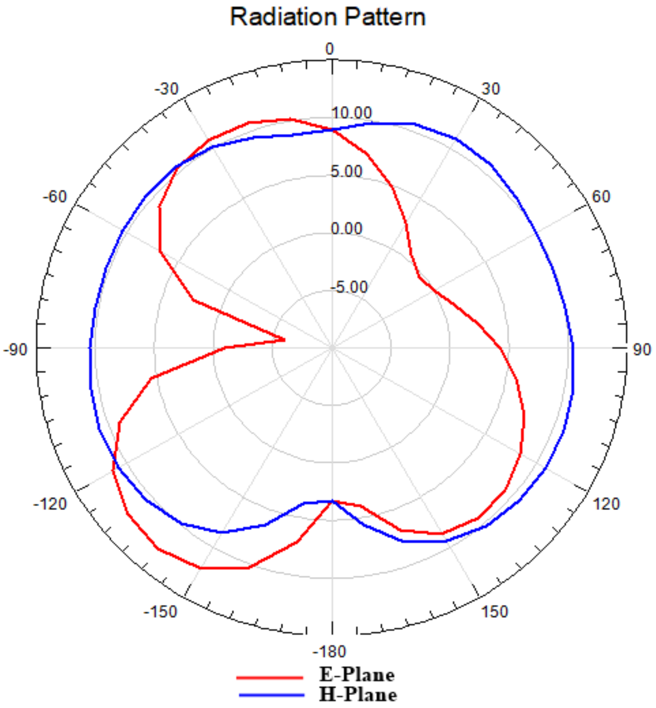


Fig 3.11: Radiation Pattern of UWB antenna

From the gain plot and two-dimensional radiation pattern shown in fig 3.10 and 3.11, Radiation pattern in E-plane is directional. It is bidirectional in H-plane with maximum in the direction of $\phi = 110^0$ and $\phi = -110^0$.

3.5.3 UWB Antenna with Truncated Edges

Antenna design is optimized to obtain an improved UWB response by removing arc shaped parts from the edges on the patch as shown in fig 3.12. The arcs are of 1mm radius each.

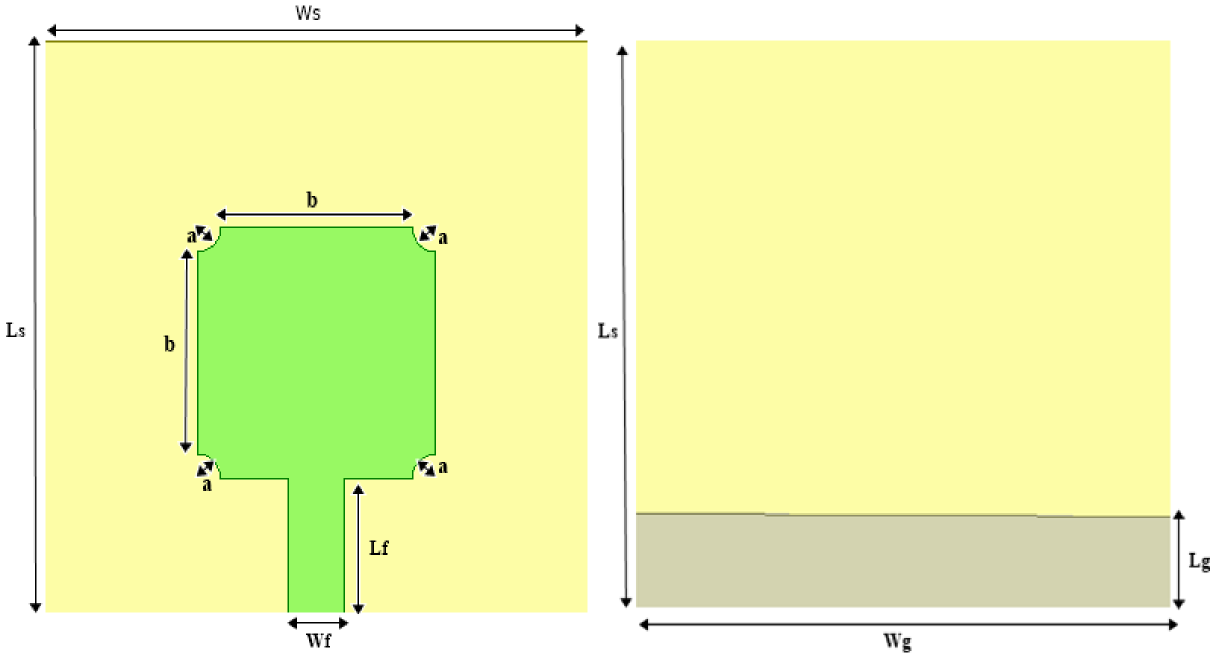


Fig 3.12: UWB Antenna with Truncated Edges

The dimensions of the UWB antenna with truncated edges are shown in table 3.3.

Table 3.3: Dimensions of UWB Antenna with truncated edges

PARAMETER	VALUE (in mm)
Length of the Substrate (L_s)	24
Width of the Substrate (W_s)	24
b	8.5
Arc Radius (a)	1
Length of the Feed (L_f)	5.7
Width of the Feed (W_f)	2.5
Length of the Ground (L_g)	4
Width of the Ground (W_g)	24

Changing the shape of the patch changes the electrical length of the current and hence the response changes. A parametric analysis is carried out to find the dimensions of the arc and the simulated results are shown in figure 3.13.

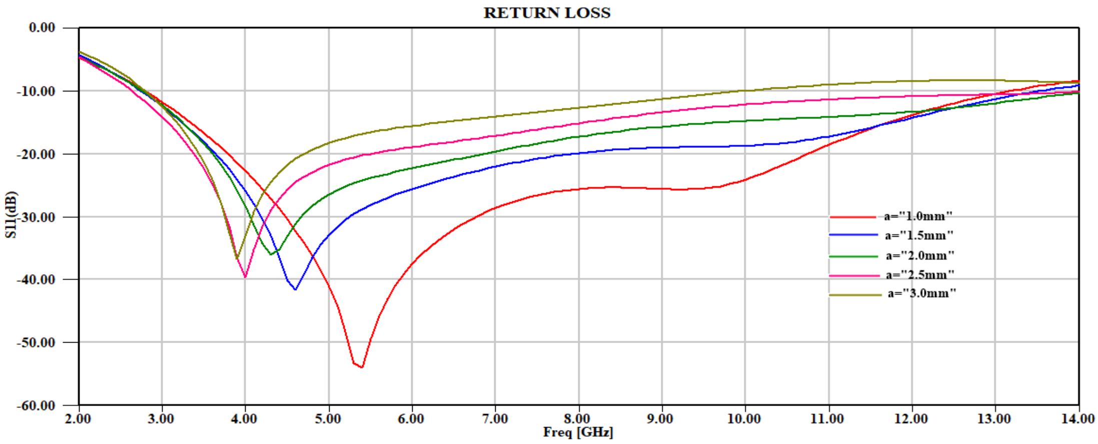


Fig 3.13: Arc length Parametric analysis results

From the arc length parametric analysis results shown in fig 3.13, better result is obtained when arc radius is 1mm. Return loss and VSWR of the antenna with truncated edges are shown in fig 3.14 and fig 3.15 respectively.

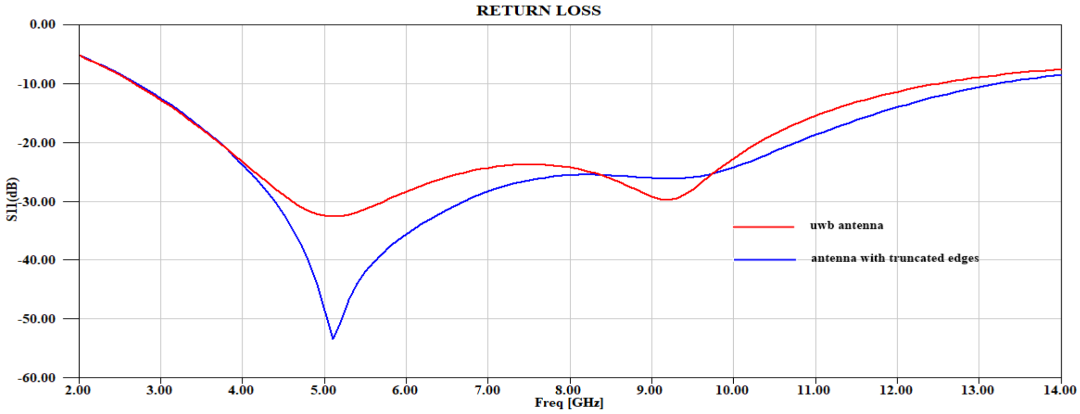


Fig 3.14: Return Loss of UWB antenna truncated edges

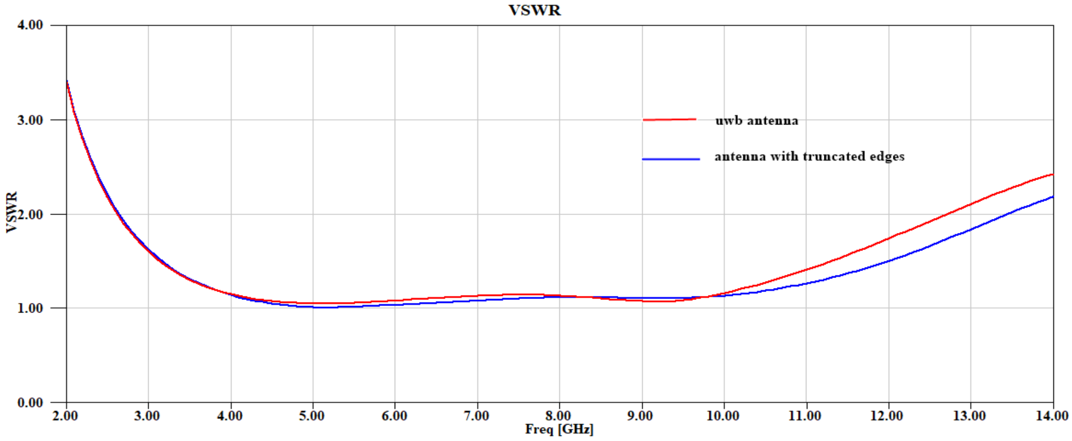


Fig 3.15: VSWR of UWB antenna truncated edges

From the simulated return loss shown in fig 3.14, return loss is less than -10dB in the frequency range of 2.8GHz -13GHz and minimum return loss of -52dB is obtained at -5.2GHz. Improved return loss is obtained with the UWB antenna with truncated edges compared to the previous antenna return loss.

From the simulated VSWR shown in fig 3.15, VSWR<2 in the frequency range of 2.8GHz -13GHz. VSWR has also improved compared to previous antenna.

Three-dimensional gain and two-dimensional radiation pattern of antenna are shown in fig 3.16 and fig 3.17 respectively.

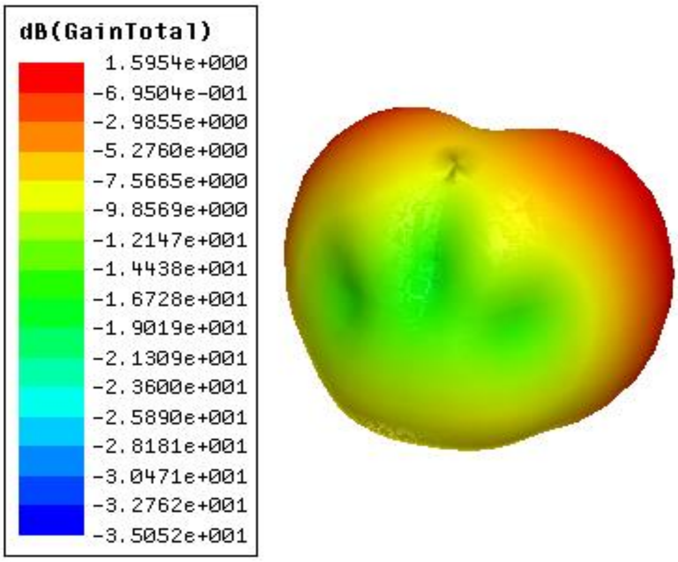


Fig 3.16: Gain plot of UWB antenna with truncated edges

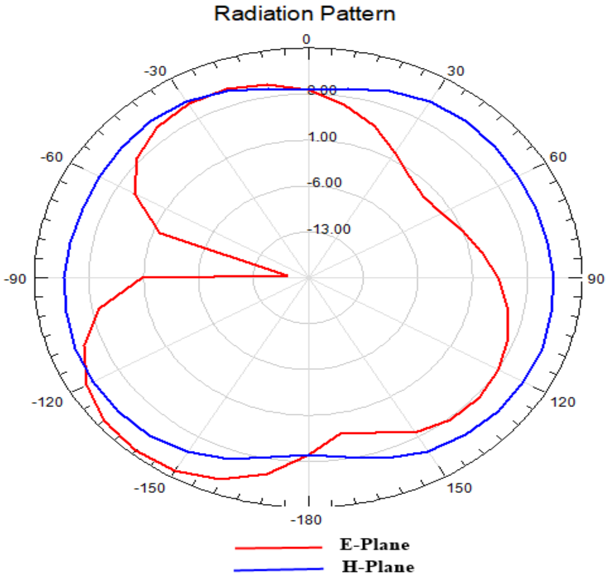
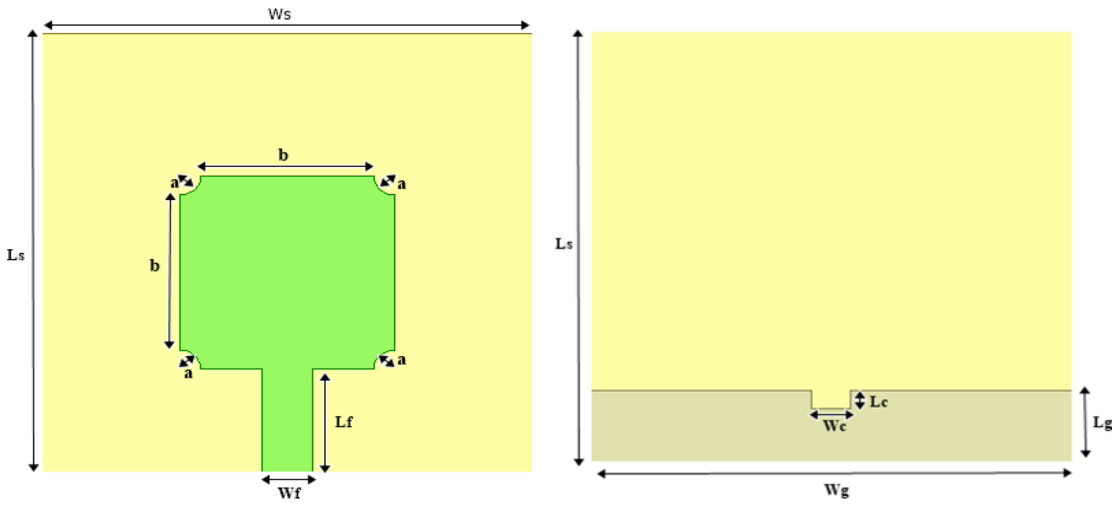


Fig 3.17: Radiation Pattern of UWB antenna with truncated edges

From the gain plot and two-dimensional radiation pattern shown in fig 3.16 and fig 3.17, radiation pattern in E-plane is maximum is directional. Radiation pattern in H-plane is bidirectional maximum in the direction of $\phi = 110^0$ and $\phi = -110^0$.

3.5.4 Final UWB Antenna

The UWB response is further improved by using a cut in the partial ground as shown in fig 3.18.



Front View **Back View**

Fig 3.18: Final UWB ANTENNA

The dimensions of the Final UWB antenna are mentioned in table 3.4

Table 3.4: Dimensions of Final UWB Antenna

PARAMETER	**VALUE (in mm)**
Length of the Substrate (L_s)	24
Width of the Substrate (W_s)	24
Arc Radius (a)	1
b	8.5
Length of the Feed (L_f)	5.7
Width of the Feed (W_f)	2.5
Length of the Cut (L_c)	1
Width of the Cut (W_c)	1
Length of the ground (L_g)	4

The dimensions of the cut are found by parametric analysis and the results of parametric analysis are shown in fig 3.19.

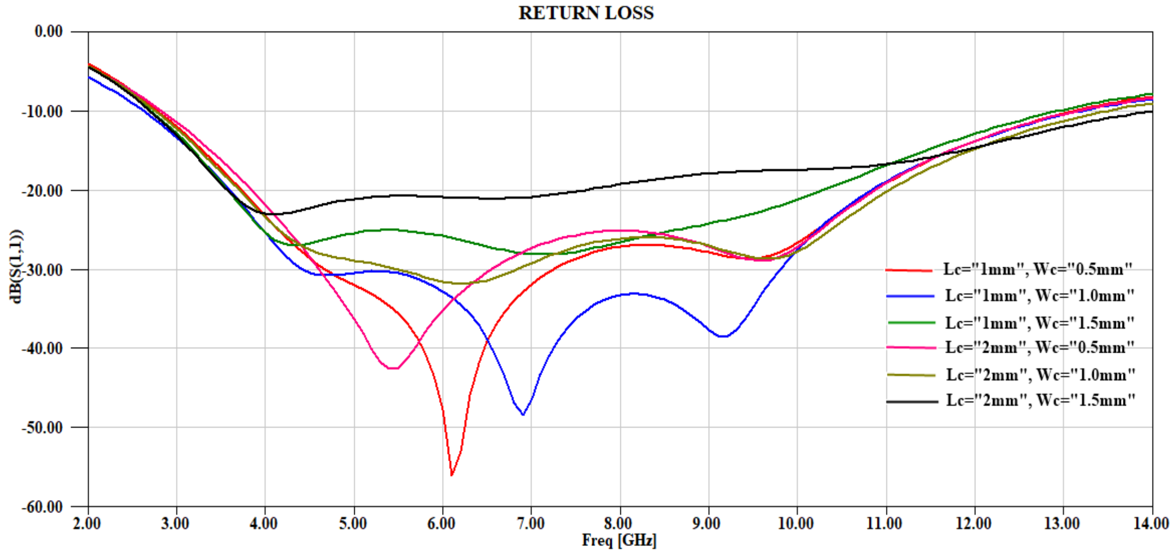


Fig 3.19: Ground cut Parametric analysis results

From the parametric analysis results shown in fig 3.19 better result is obtained when length and width of the cut are 1mm each. Return loss and VSWR of final UWB antenna are shown in fig 3.20 and 3.21 respectively.

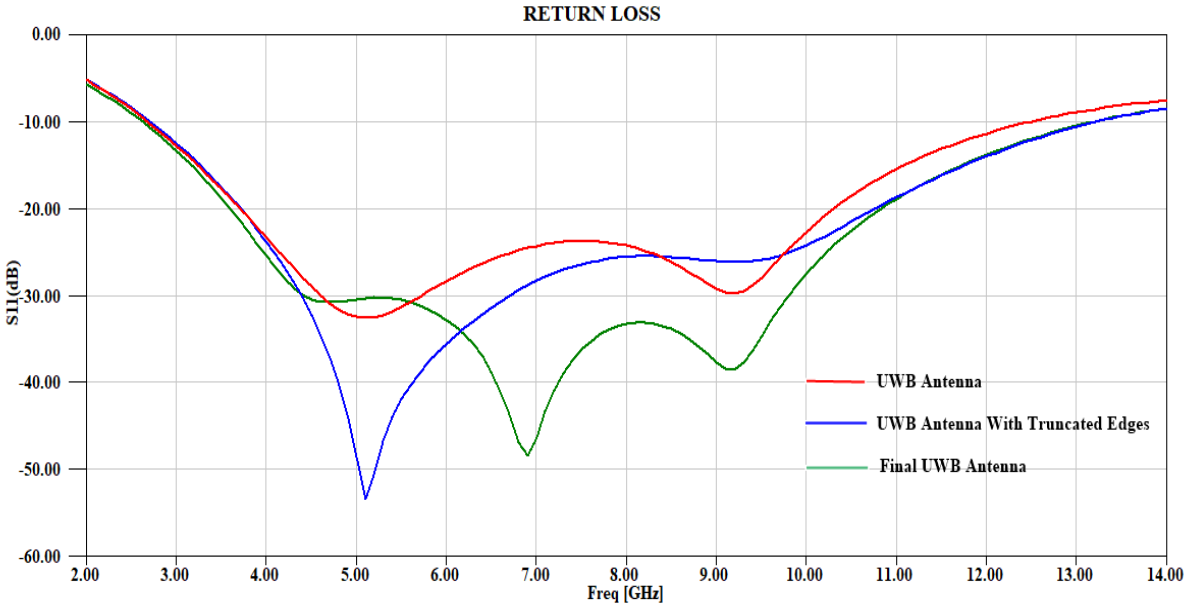


Fig 3.20: Return Loss of final UWB antenna

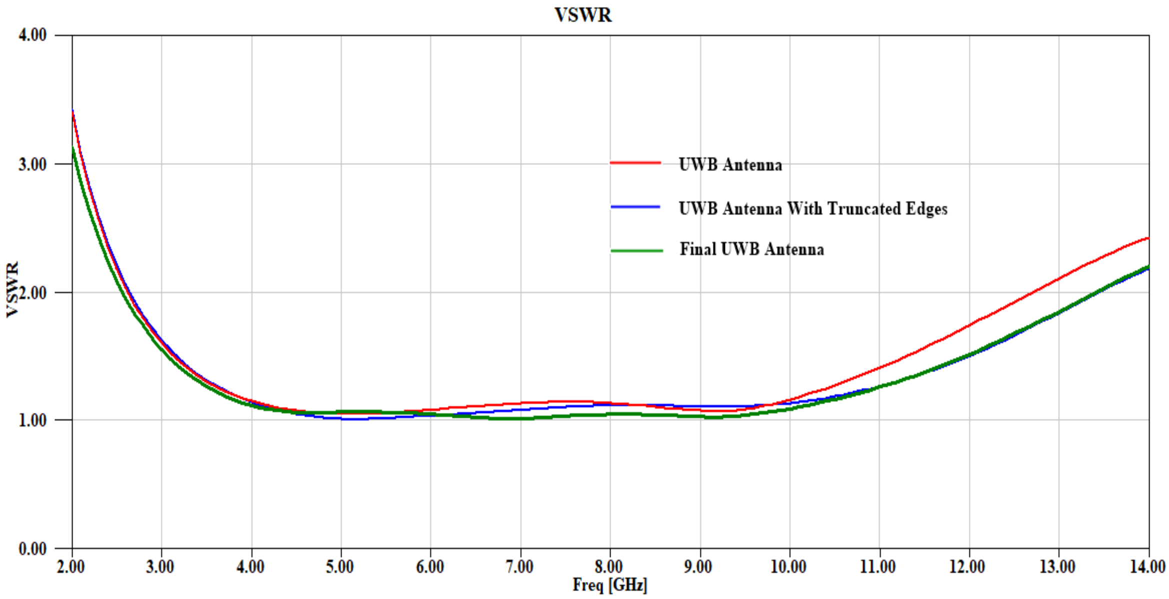


Fig 3.21: VSWR of final UWB antenna

From the simulated return loss and VSWR of final UWB antenna shown in fig 3.20 and fig 3.21 return loss is less than -10dB and VSWR is less than 2 in the range of 2.7GHz - 13GHz. Better UWB response was obtained for the final antenna design.

Gain and radiation pattern of antenna are shown in the fig 3.22 and 3.23 respectively.

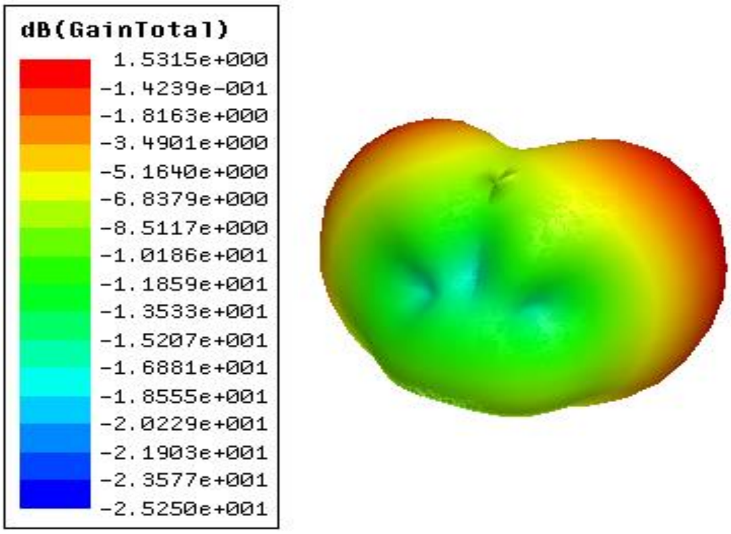


Fig 3.22: Gain Plot of final UWB antenna

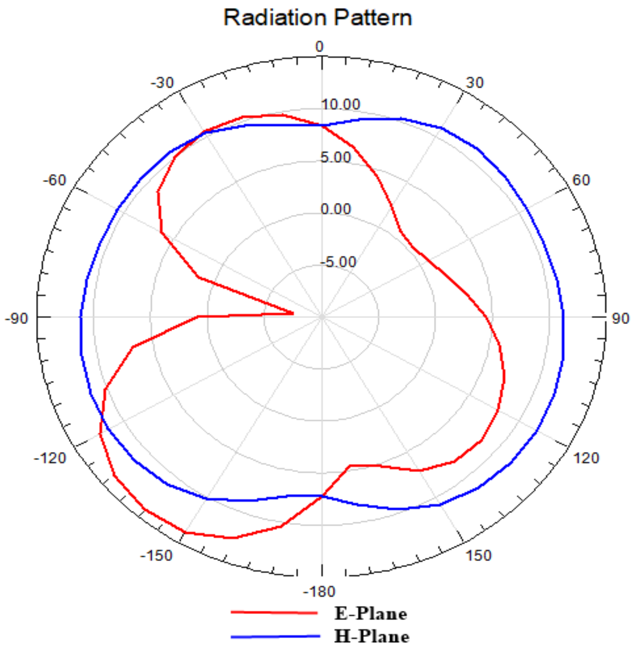


Fig 3.23: Radiation Pattern of final UWB antenna

From the gain and radiation pattern shown in fig 3.22 and fig 3.23, radiation pattern in E-plane is directional. Radiation pattern in H-plane is bidirectional with maximum in the direction of $\phi = 120^0$ and $\phi = -120^0$.

CHAPTER 4

BAND NOTCHED UWB ANTENNA

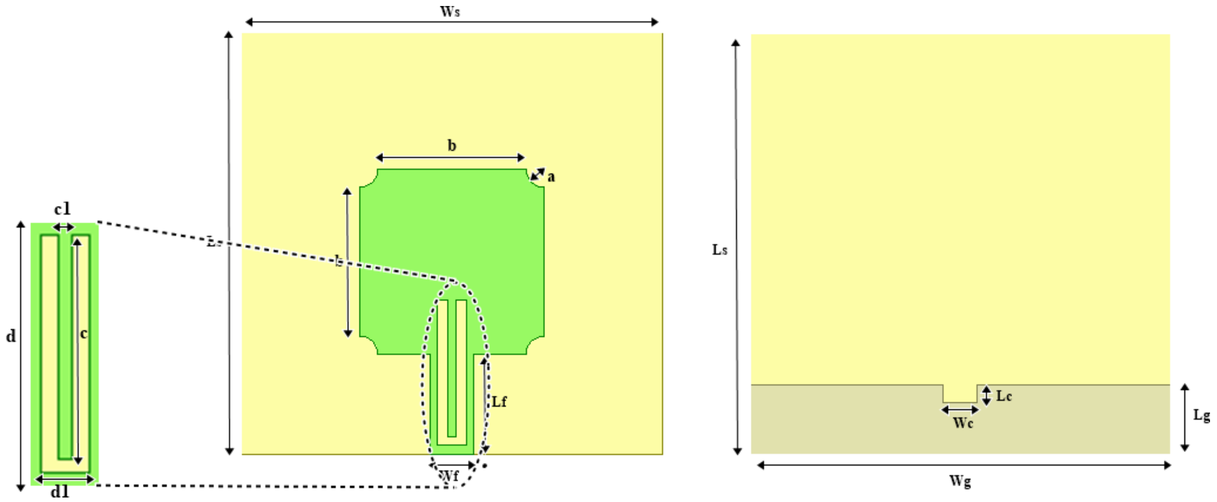
4.1 INTRODUCTION TO BAND NOTCHED ANTENNAS

In 2002, the FCC in the US authorized the unlicensed use of the ultrawideband (UWB) frequency spectrum for commercial applications in the range from 3.1 to 10.6 GHz with an emission limit of -41.3 dBm/MHz which is near to the thermal noise floor. UWB communication systems operating in such a wide frequency band and low power emission level could easily be interfered by the existing nearby communication systems such as the Wireless Local Area Networks (WLANs) operating in the frequency bands of 2.45GHz (2.4GHz – 2.484 GHz), 5.25GHz (5.15GHz – 5.35GHz) and 5.75GHz (5.725GHz – 5.825GHz) and the Worldwide Interoperability for Microwave Access (WiMAX) systems operating in the 2.35GHz (2.3GHz - 2.4GHz), 2.6GHz (2.5GHz – 2.69GHz), 3.35GHz (3.3GHz - 3.4GHz), 3.5GHz (3.4GHz – 3.6 GHz), 3.7GHz (3.6GHz - 3.8GHz) and 5.8GHz (5.725GHz – 5.85GHz) bands.

In general, the design procedure for a band-notched antenna can be described as follows. An UWB antenna without band-notched function is designed to have good impedance matching over the UWB, which is used as a reference antenna. Proposed resonant structures are added to the reference antenna to create notches at some specific frequencies. The dimensions of the resonant structures can be used to control the centre frequencies and bandwidths of the notches. Different designs have been proposed to realize the band-notched characteristic for UWB planar monopole antennas. These include using parasitic elements near the ground or patch, folded strips, split-ring resonators (SRRs), Complementary Split Ring Resonators (CSRR), quarter-wavelength tuning stubs, meander-ground structures, resonated cells on the coplanar-waveguide (CPW), fractal tuning stub, slots on the radiator or ground, and slots or folded – strip lines along the antenna feed line. However, most of these designs targeted at creating a single-notched band and only one design targeted at a triple-notched band using meander lines.

4.2 DESIGN AND RESULTS OF BAND NOTCHED UWB ANTENNA

In the entire UWB range, there are several narrow band frequencies present, some of which are WLAN, WiMAX, X-Band. These may cause some interference to the antenna. A band notched UWB antenna designed to reject the WLAN frequency range of 5.15GHz – 5.825GHz is shown in below fig 4.1. A vertical stub is inserted into the slot made on the feedline to obtain band notching characteristics.



Front View **Back View**

Fig 4.1: Band Notched UWB Antenna

The dimensions of the Band Notched UWB antenna are mentioned in table 4.1

Table 4.1: Dimensions of band notched UWB Antenna

PARAMETER	**VALUE (in mm)**
Length of the Substrate (L_s)	24
Width of the Substrate (W_s)	24
Arc Radius (a)	1
b	8.5
Length of the Feed (L_f)	5.7
Width of the Feed (W_f)	2.5
Length of the Cut (L_c)	1
Width of the Cut (W_c)	1
Stub Length (c)	7.7
Stub Width (c1)	0.6
Slot Length (d)	8.2
Slot Width (d1)	1.6

A parametric analysis is carried out to observe the effect of stub width, stub length and slot width on the notch range and centre frequency and the results are shown in fig 4.2.

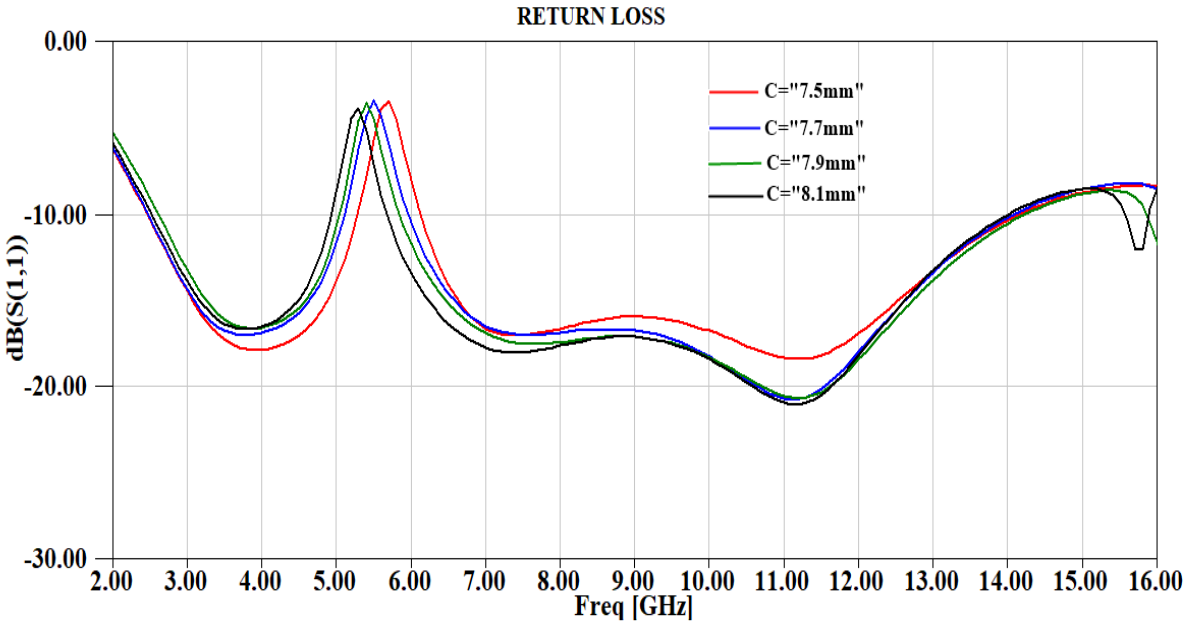


Fig.4.2(a): Effect of stub length

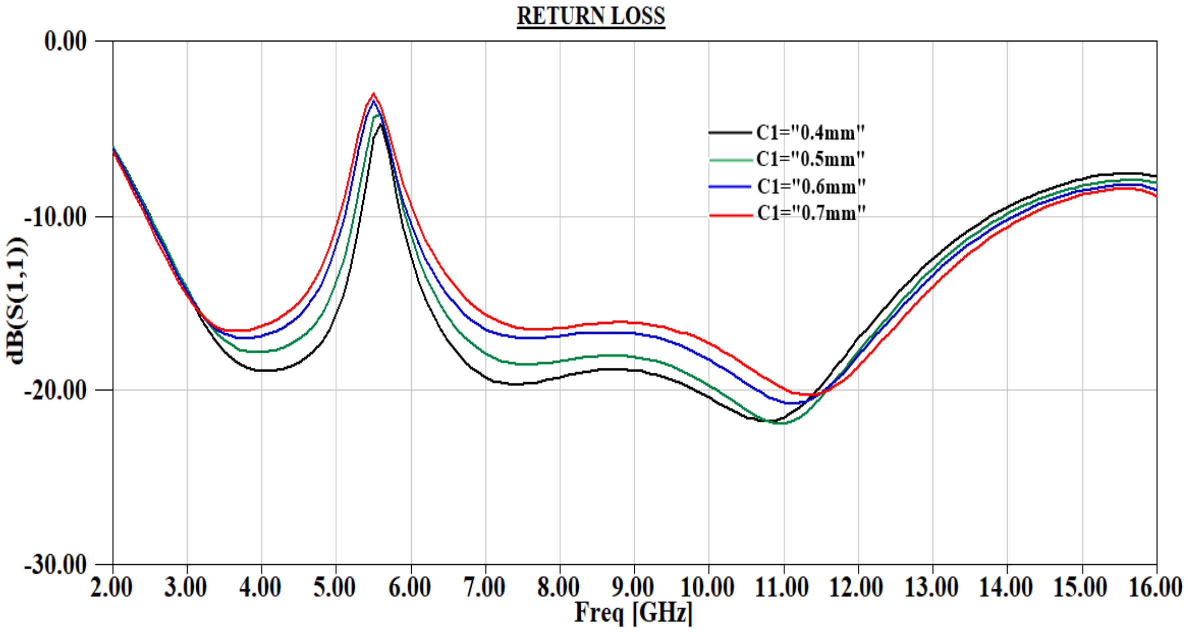


Fig.4.2(b): Effect of stub width

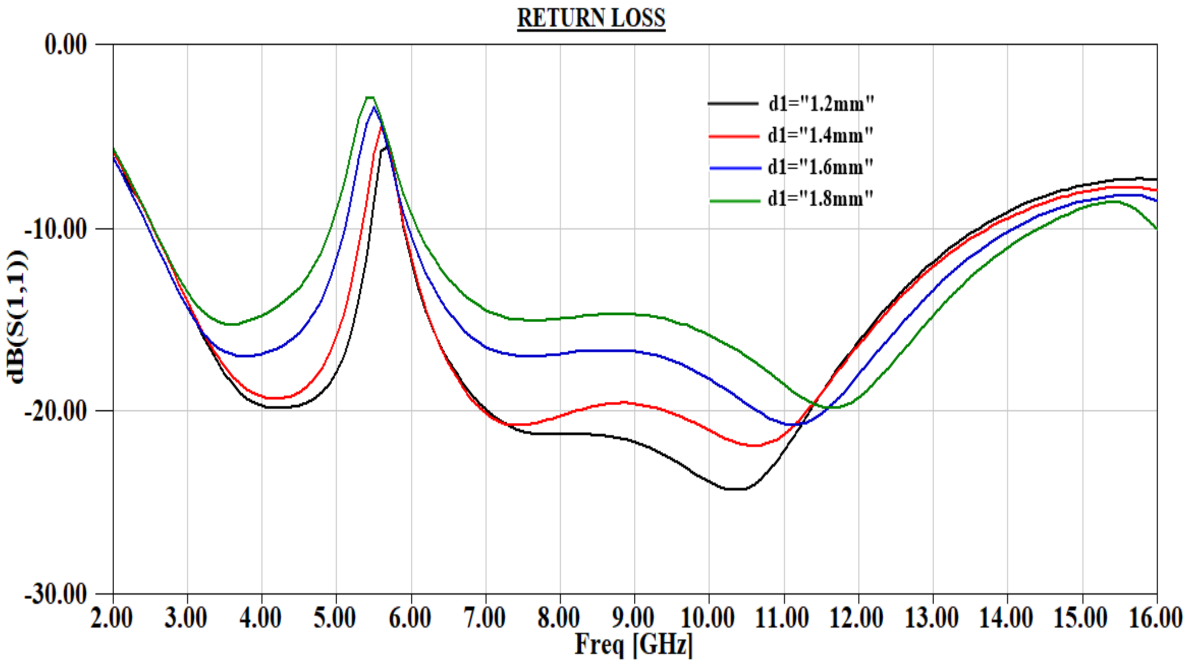


Fig.4.2(c): Effect of slot width

From the simulated results shown in fig 4.2(a), varying the stub length from 7.5mm to 8.1mm shifted the centre frequency of notch band from 5.7 to 5.3GHz. Increasing the stub length decreases the centre frequency as length is inversely proportional to frequency as shown in equation (4.1)

$$L_{stub} = \frac{\lambda_g}{4} = \frac{\lambda}{4\sqrt{\epsilon_{reff}}} = \frac{C}{4f\sqrt{\epsilon_{reff}}} \text{.............................}(4.1)$$

Where f is the centre frequency of notch band, C is speed of light in free space, ϵ_{reff} is the effective dielectric constant.

From the parametric results shown in fig 4.2(b) and fig 4.2 (c), varying the stub width from 0.4mm to 0.7mm and slot width from 1.2mm to 1.8mm, increased the notch frequency range and return loss at centre frequency. The desired results are obtained when stub length is 7.7mm, stub width is 0.6mm and slot width is 1.6mm.

Simulated return loss and VSWR of band notched UWB Antenna are shown in fig 4.3 and 4.4 respectively.

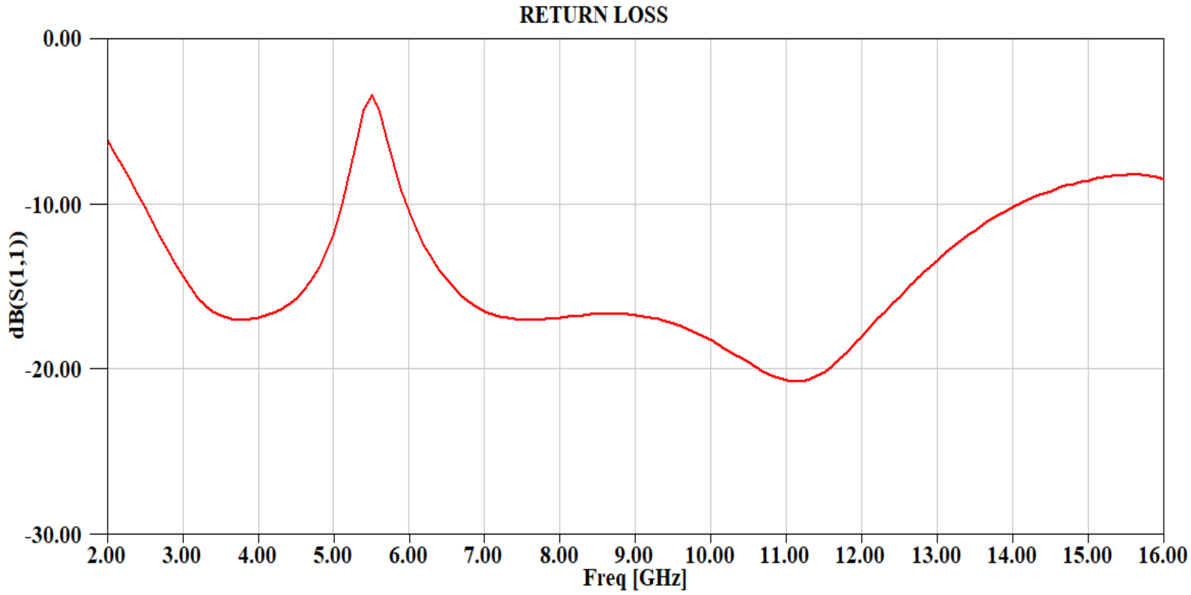


Fig 4.3: Return Loss of Band Notched UWB Antenna

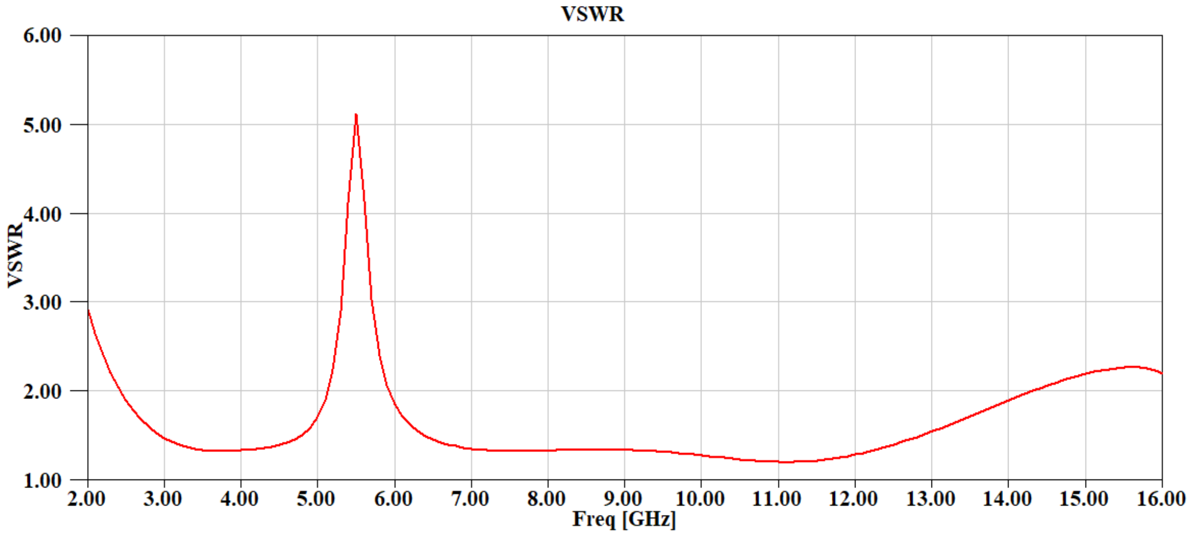


Fig.4.4: VSWR of Band Notched UWB Antenna

From the simulated return loss and VSWR of Band Notched UWB antenna shown in fig 4.3 and fig 4.4, antenna is resonating from 2.5GHz – 14GHz with notch band in the range of 5.1GHz – 5.95GHz. The centre frequency of notch band is 5.5GHz with a return loss of -3.5dB and VSWR of 5.2.

The three-dimensional gain and two-dimensional radiation pattern at the passband frequency 7.3GHz and stop band frequency 5.5GHz are shown in fig 4.5 and 4.6 respectively.

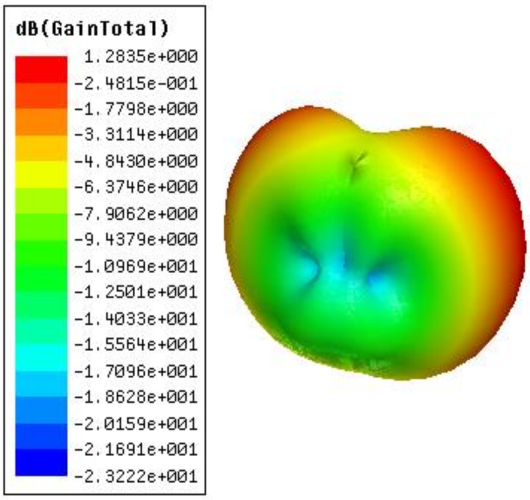


Fig.4.5(a): Gain at Pass Band frequency 7.3GHz

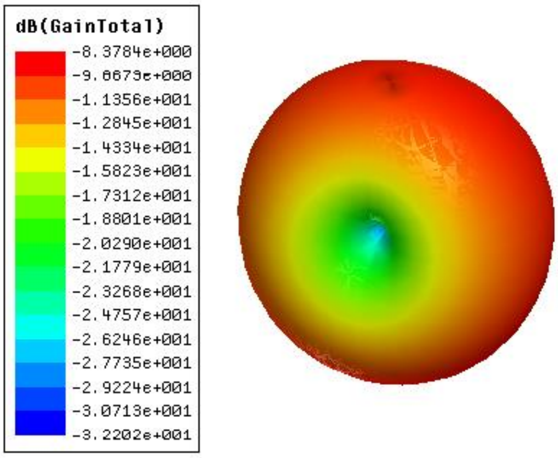


Fig4.5(b): Gain at Stop Band frequency 5.5GHz

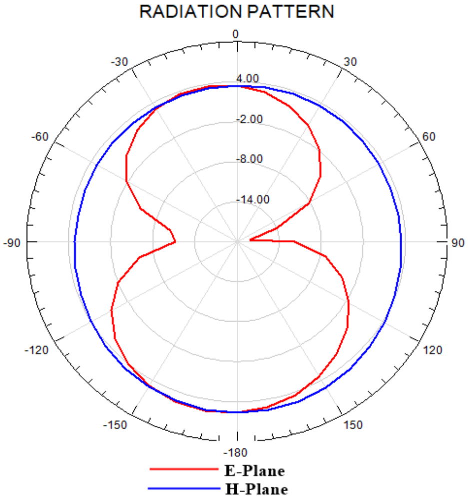


Fig.4.6(a): Radiation pattern at stop band frequency 5.5GHz

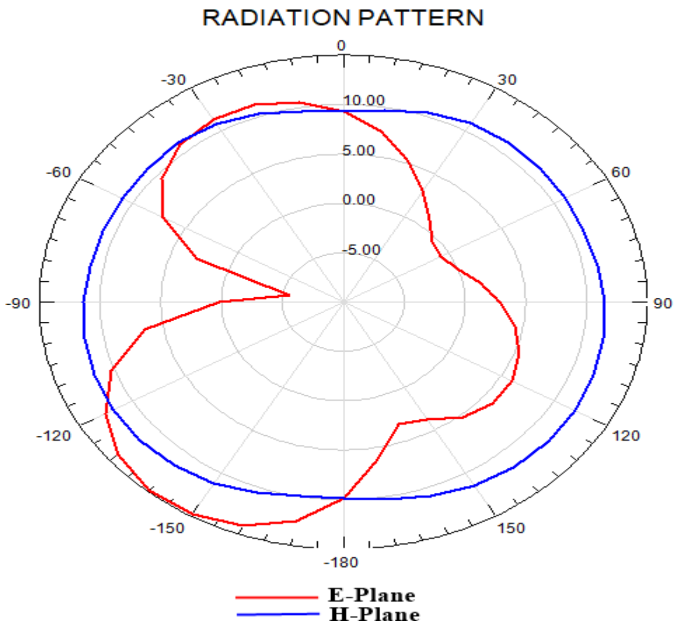


Fig.4.6(b): Radiation pattern at pass band frequency 7.3GHz

From the gain and the two-dimensional radiation pattern shown in fig 4.5 and fig 4.6, Band Notched UWB antenna’s radiation pattern in E-plane and H-plane is bidirectional at stop band frequency of 5.5GHz. Radiation pattern in E-plane is directional and H-plane is bidirectional at pass band frequency of 10GHz

The surface current distribution at pass band frequency 7.3GHz and stop band frequency 5.5GHz are shown in fig 4.7.

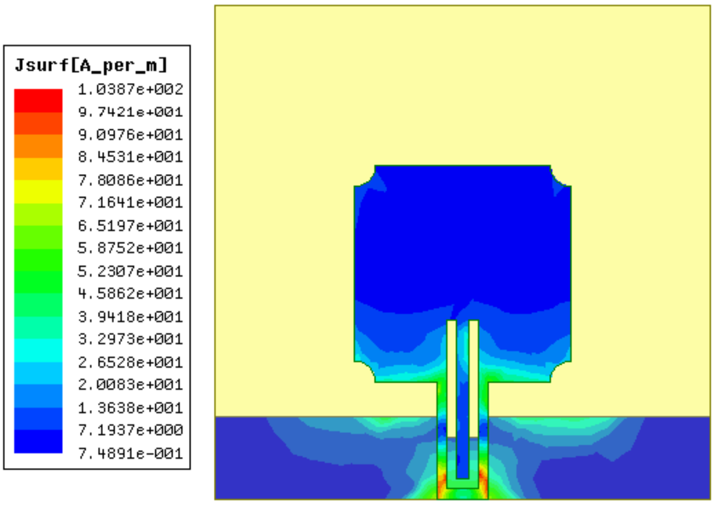


Fig.4.7(a): Surface current distribution at pass band frequency 7.3GHz

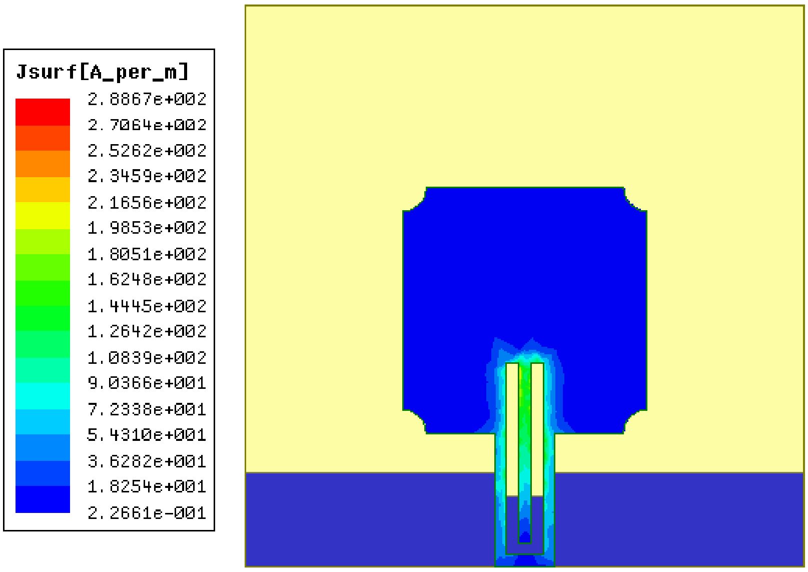


Fig.4.7(b): Surface current distribution at stop band frequency 5.5GHz

The surface current distribution of Band Notched UWB antenna shown in Fig 4.7 (a) indicates that at a pass band frequency of 7.3GHz the stub is not getting affected and the surface current is distributed on to the ground and patch and the antenna is radiating. Fig 4.7(b) indicates that majority of surface current at notch frequency of 5.5GHz is concentrated on the stub and the antenna is not radiating.

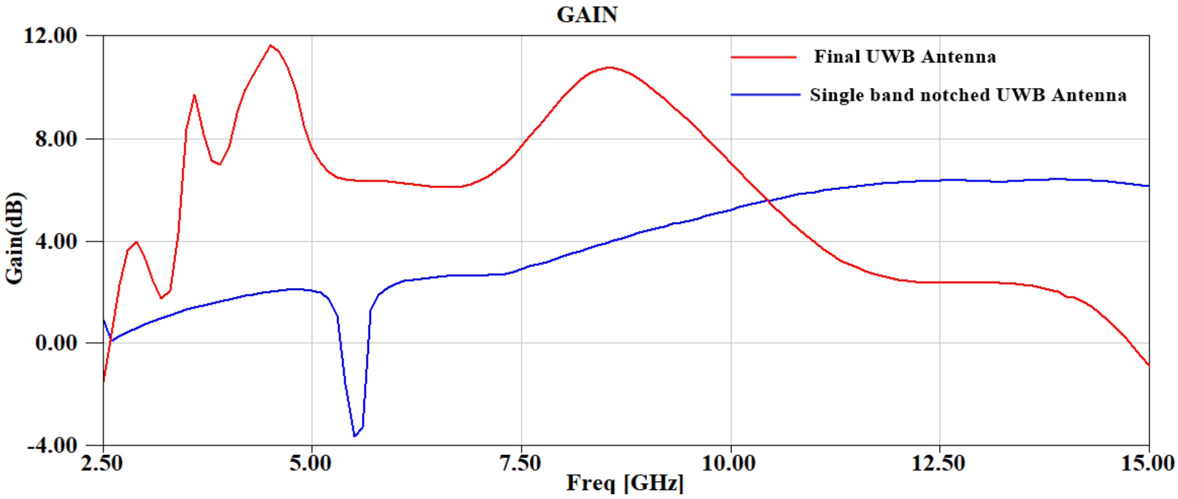


Fig 4.8: Gain plot of Final UWB Antenna and Band Notched UWB antenna

From the simulated gain plot of Final UWB Antenna and Band Notched UWB antenna shown in Fig 4.8, the gain of Final UWB antenna is acceptable in the entire operating bandwidth with a maximum gain of 11.5dB. The gain of a Band Notched UWB antenna is decreased in the notch band

CHAPTER 5

BAND NOTCHED UWB MIMO ANTENNA

5.1 MIMO DEFINITION

MIMO (multiple input, multiple output) is an antenna technology for wireless communications in which multiple antennas are used at both the source (transmitter) and the destination (receiver). The antennas at each end of the communications circuits are combined to minimize errors, optimize data speed and improve the capacity of radio transmissions by enabling data to travel over many signal paths at the same time. MIMO technology uses spatial diversity to reduce the multipath fading and interference as when same data is sent through different channels at least one copy of data reaches the receiver with less fading. It also uses spatial multiplexing where different data is sent through different antenna elements hence the channel capacity increases.

5.2 IMPORTANCE OF MIMO ANTENNAS

Multiple – input, multiple – output (MIMO) antenna systems are used in modern wireless standards, including in IEEE 802.11n, 3GPP LTE, and mobile WiMAX systems. The technique supports enhanced data throughput even under conditions of interference, signal fading, and multipath. The demand for high data rates over longer distances has been one of the primary motivations behind the development of MIMO orthogonal – frequency – division – multiplexing (OFDM) communications systems. In effect, MIMO systems use a combination of multiple antennas and multiple signal paths to gain knowledge of the communications channel. By using the spatial dimension of a communications link, MIMO systems can achieve significantly higher data rates than traditional single – input single – output (SISO) channels.

5.3 DESIGN AND RESULTS OF BAND NOTCHED UWB MIMO ANTENNA

A compact 34 x 34 x 1.6 mm^3 four element MIMO antenna with four symmetrical antenna elements placed orthogonal to each other is shown in fig 5.1. the four antenna elements are placed on FR4 epoxy substrate with a dielectric constant of 4.4. The antenna elements are so placed so as to reduce the mutual coupling between the elements. The distance between centre of one radiating element and the other is greater than quarter wavelength and less than half wavelength. The size of MIMO antenna is increased by 49 percent compared to the size of the single element band notched UWB antenna.

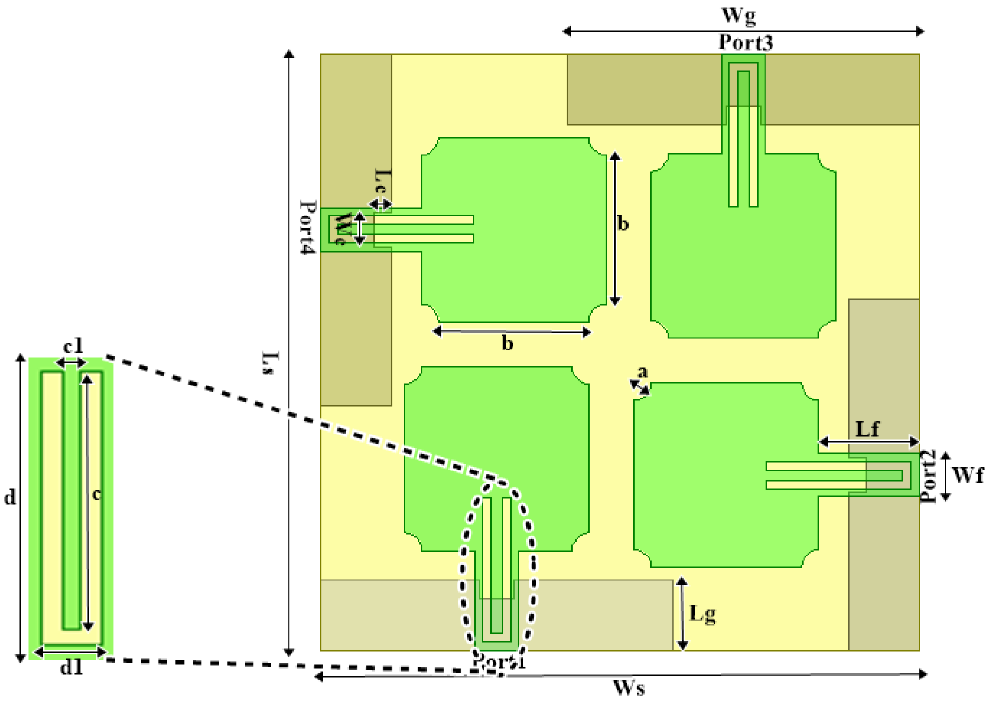


Fig 5.1: Band Notched UWB MIMO Antenna

The optimised dimensions of the antenna are shown in table 5.1

Table 5.1 Dimensions of Band Notched Ultra-Wide Band MIMO Antenna

PARAMETER	VALUE (in mm)
Length of the Substrate (L_s)	34
Width of the Substrate (W_s)	34
Length of the Gain (L_g)	4
Width of the Gain (W_g)	20
Length of the Feed (L_f)	5.7
Width of the Feed (W_f)	2.5
Arc Radius (a)	1
b	8.5
Stub Length (c)	7.7
Stub Width (c1)	0.6
Slot Length (d)	8.2
Slot Width (d1)	1.6
Length of the Cut (L_c)	1
Width of the Cut (W_c)	1

The simulated return loss of Band Notched UWB MIMO antenna is shown in Fig 5.2, Return loss of MIMO antenna is less than -10dB in the frequency range of 2.5GHz - 15GHz with notch in the range of 5.15GHz - 6GHz.

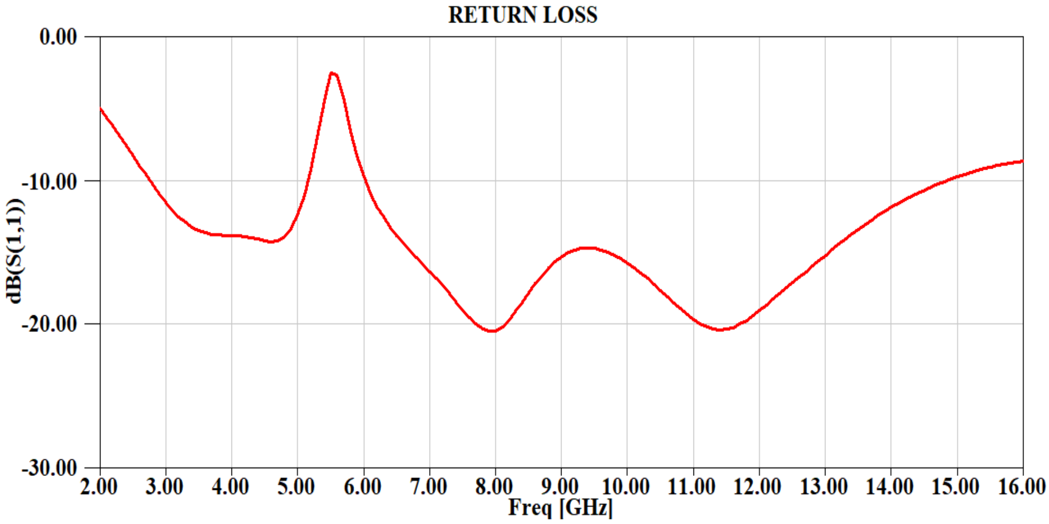


Fig 5.2: Return Loss of Band Notched UWB MIMO antenna

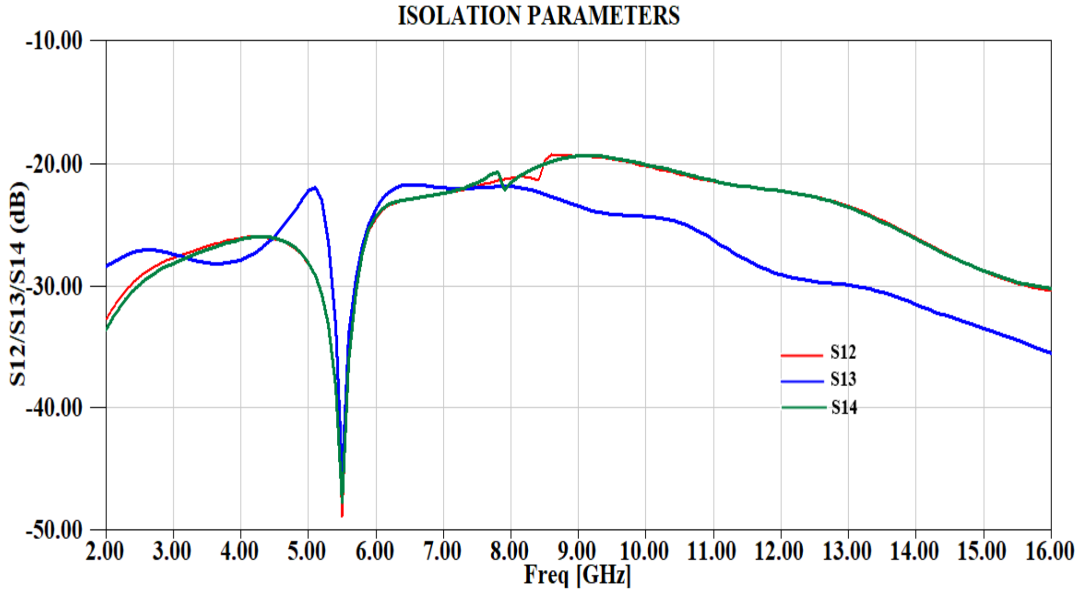


Fig 5.3: Isolation Parameters of Band Notched UWB MIMO antenna

The simulated isolation parameters of Band Notched UWB MIMO antenna are shown in Fig 5.3. From the isolation parameters s12 < -19dB and S14 < -19dB in the entire operating bandwidth and high isolation is achieved between first and third elements with s13 < - 22dB.

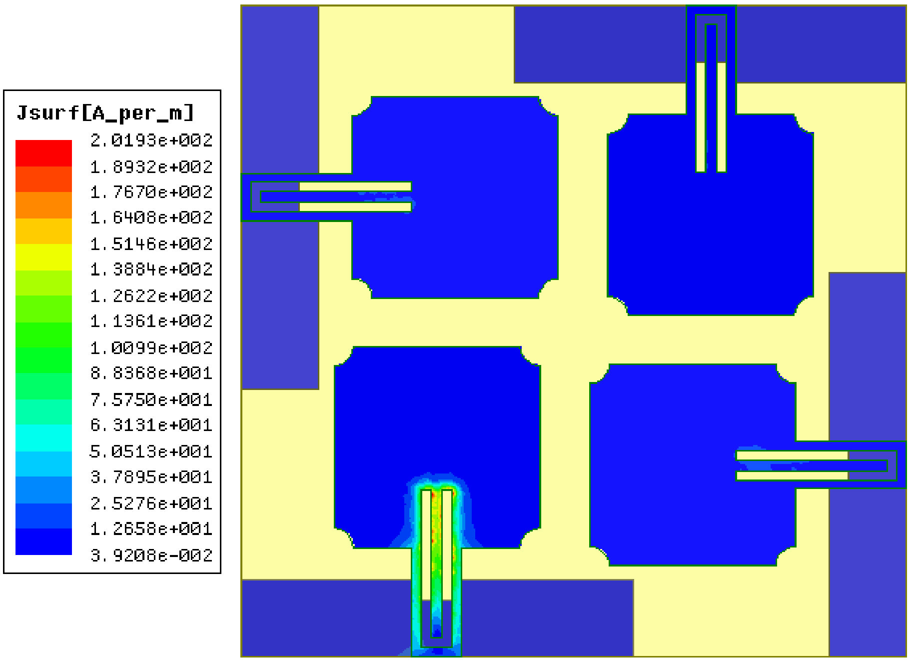


Fig 5.4(a): Surface current distribution at stop band frequency 5.5GHz

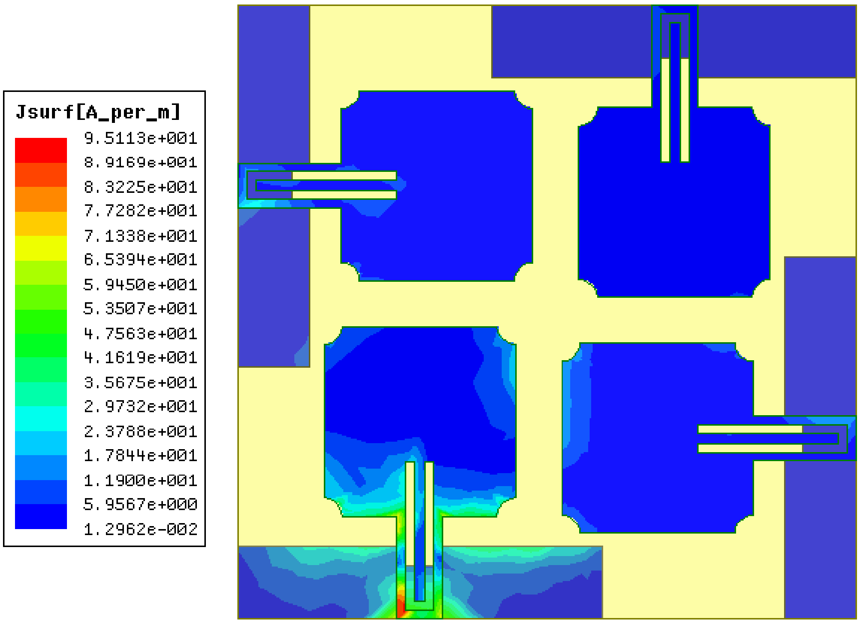
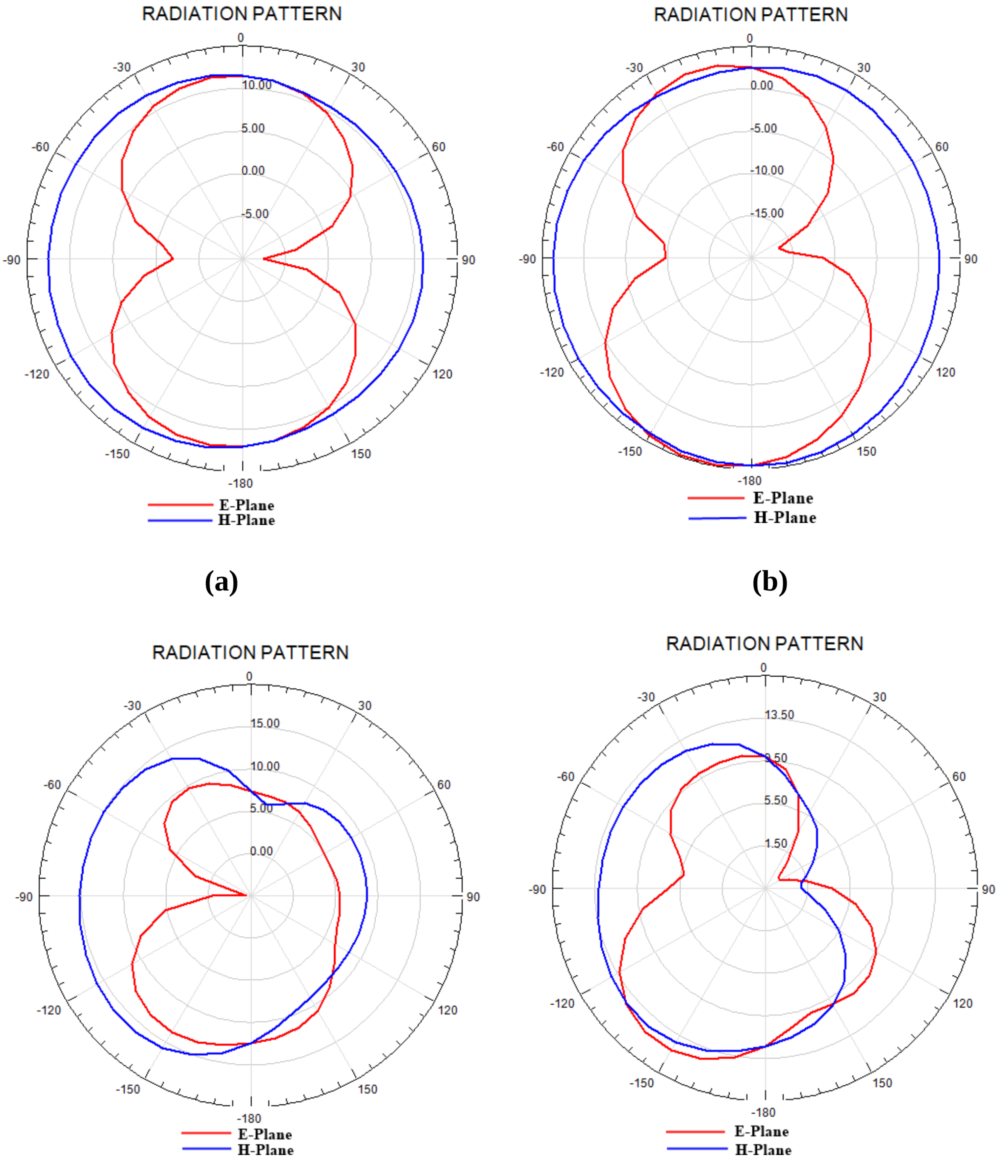


Fig 5.4(b): Surface current distribution at pass band frequency 7.3GHz

From the surface current distribution shown in Fig 5.4(a) majority of surface current at stop band frequency 5.5GHz is concentrated along the stub and the antenna element is not radiating and no surface current is being coupled to other antenna elements. From Fig 5.4(b) negligible amount of surface current in element 1 is being coupled to other antenna elements when port1 is excited and all the other ports are terminated with matched termination as the antenna elements are placed orthogonal to each other.



(a) (b)

(c) (d)

Figure 5.5: Radiation pattern at (a) 4GHz (b) 5.5GHz (c) 8GHz (d) 10GHz in E-Plane and H-Plane

The simulated radiation patterns of E-Plane and H-plane at 4GHz, 5.5GHz, 8GHZ and 10GHz are shown in Figure 5.5(a-d). The radiation pattern at 4GHz in fig 5.5(a) and at 5.5GHz in fig 5.5(b) is bidirectional in E-plane and H-Plane. The radiation pattern at 8GHz in fig 5.5(c) and at 10GHz in fig 5.5(d) , both H-plane and E-plane are directional with maximum at $\phi = -140^0$. The antenna is exhibiting bidirectional characteristics at the lower resonant frequencies and directional characteristics at higher resonant frequencies.

5.4 MIMO DIVERSITY PARAMETERS

Multipath fading effect is minimized by MIMO antenna due to spatial diversity. MIMO diversity parameters are an important performance indicators of MIMO antenna.

5.4.1 ENVELOPE CORRELATION COEFFICIENT

ECC indicates the amount of mutual coupling existing between the antenna elements. Lower ECC values indicates good isolation between the elements. An ECC of 0.5 and less than 0.5 is acceptable. It can be calculated from the S-parameters.

It can be calculated from the S-parameters using (5.1).

$$\mathrm{ECC}_{ij} = \frac{|\sum_{n=1}^{N} S_{i,n}{}^{*} S_{n,j}|^2}{|\prod_{k=i,j}(1-\sum_{n=1}^{N} S_{k,n}{}^{*} S_{n,k})|} \text{…….(5.1)}$$

Where i and j are the port numbers and N is the number of ports.

$$ECC_{12} = \frac{|S_{11}{}^{*}S_{12}+S_{12}{}^{*}S_{22}+S_{13}{}^{*}S_{32}+S_{14}{}^{*}S_{42}|^2}{(1-|S_{11}|^2-|S_{21}|^2-|S_{31}|^2-|S_{41}|^2)(1-|S_{12}|^2-|S_{22}|^2-|S_{32}|^2-|S_{42}|^2)} \text{……….(5.2)}$$

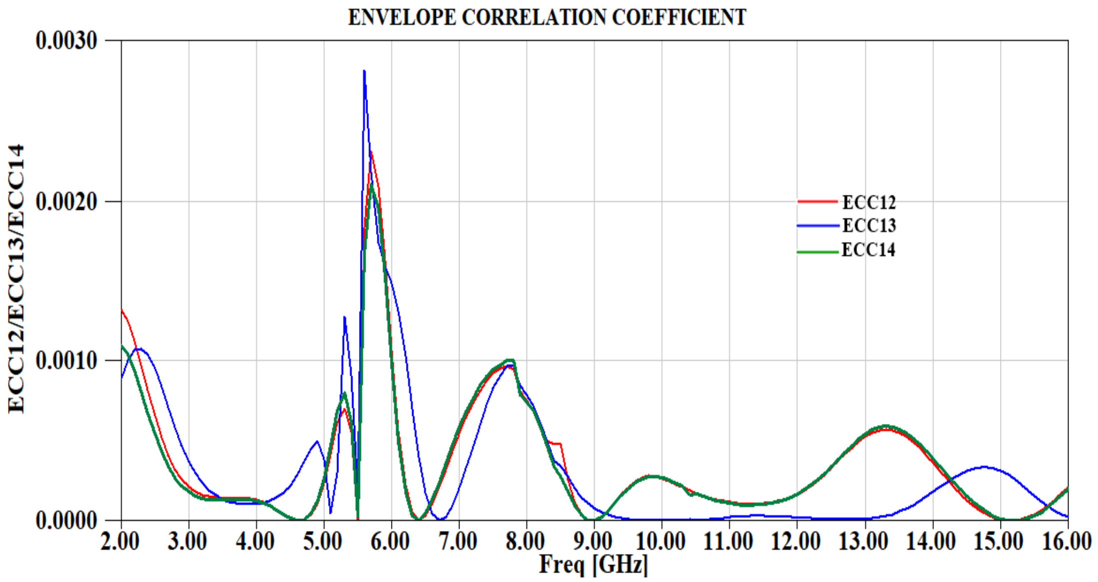


Fig 5.6: Envelope Correlation Coefficient

For the proposed single band notched UWB MIMO antenna, the ECC is calculated from S-parameters of antenna element 1 and 2 using (5.2). From the simulated Envelope Correlation Coefficient shown in fig 5.6, ECC value is less than 0.003 in the entire operating frequency range and it is less than the acceptable value. Hence mutual coupling between MIMO antenna elements is very less.

5.3.2 DIVERSITY GAIN

Diversity gain is another important parameter which has an inverse relation with ECC. It should be greater than 9.5dB and the maximum value is 10dB.From the simulated diversity gain shown in fig 5.7, diversity gain is greater than 9.9dB in the entire operating frequency range. It can be calculated using (5.3).

$$DG_{ij}=10\sqrt{1-ECC_{ij}{}^{2}}\ldots\ldots\ldots\ldots (5.3)$$

Where *i* and *j* are the port numbers

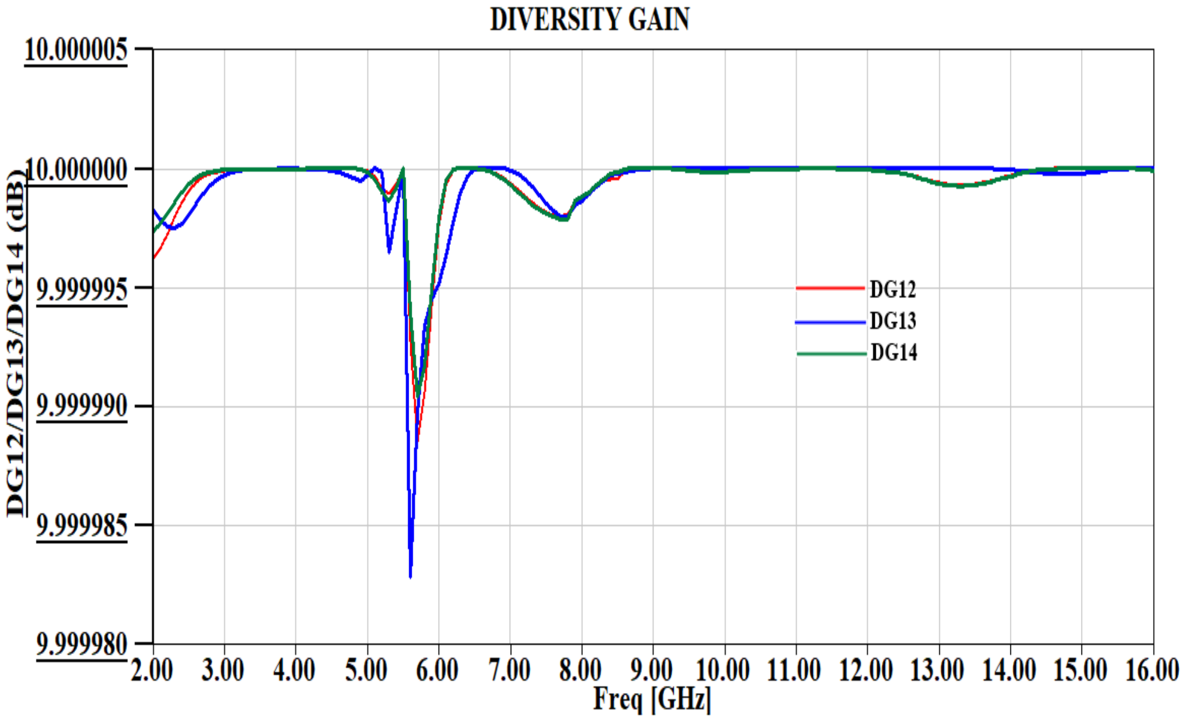


Fig 5.7: Diversity Gain

5.3.3 TOTAL ACTIVE REFLECTION COEFFICIENT

TARC is another important parameter which is calculated from the S-parameters. It should be less than 0 dB and from the simulated total active reflection coefficient shown in Fig 5.8, TARC is less than -10dB in the entire operating bandwidth. TARC can be calculated using (5.4).

$$\text{TARC}=\frac{\sqrt{|S_{11}+S_{12}+S_{13}+S_{14}|^{2}+|S_{21}+S_{22}+S_{23}+S_{24}|^{2}+|S_{31}+S_{32}+S_{33}+S_{34}|^{2}+|S_{41}+S_{42}+S_{43}+S_{44}|^{2}}}{\sqrt{4}}\ldots (5.4)$$

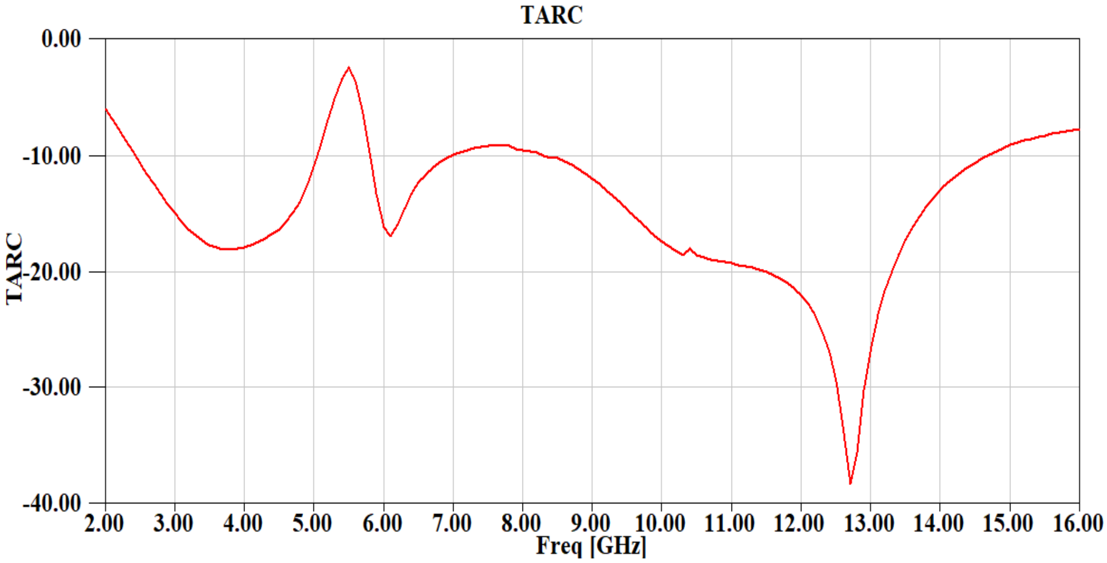


Fig 5.8: Total Active Reflection Coefficient

5.3.4 MEAN EFFECTIVE GAIN

Mean Effective Gain can be taken as the ratio of mean received power to mean incident power. MEG should be less than -3dB. From the Mean Effective Gain shown in fig 5.9, MEG is less than -6dB in the entire operating frequency range. It can be calculated using (5.5).

$$\mathrm{MEG_i} = 0.5\left[1 - \sum_{j=1}^{N} |S_{ij}|^2\right] \text{…..(5.5)}$$

Where i and j are the port numbers and N is the total number of ports.

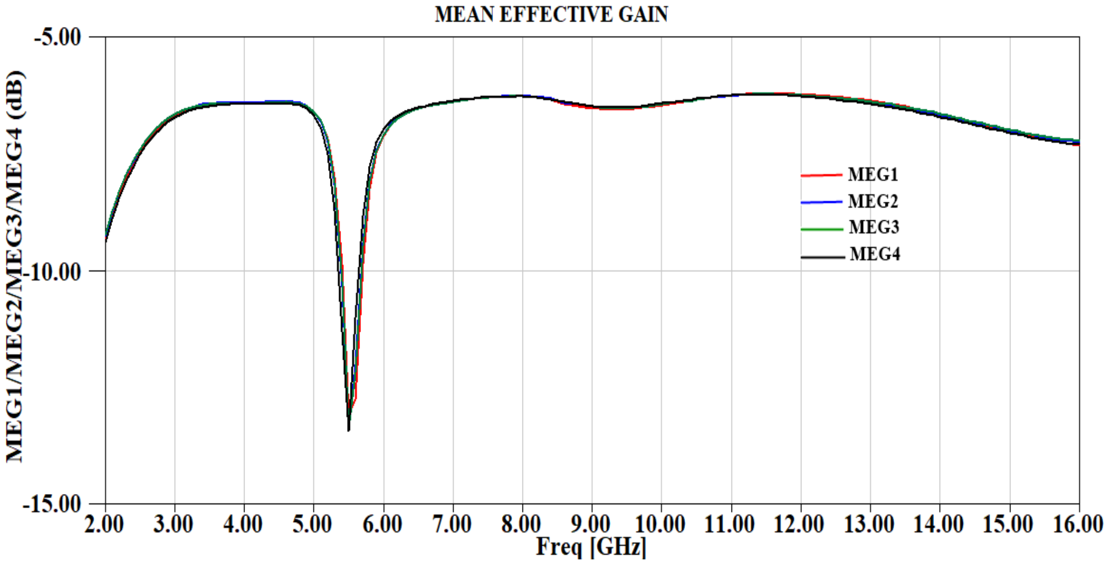


Fig 5.9: Mean Effective Gain

5.5 Performance of Various Antenna Designs

Performance of various antenna designs is shown in table 5.2

Table 5.2: Performance of various antenna designs.

Design	Frequency Range	Return Loss S11(dB)	Maximum Gain	Bandwidth
Basic Square patch antenna	6.17GHz – 6.49GHz	-19.9 dB	2.9dB	320MHz
UWB Antenna	2.8GHz – 12.3GHz	-32 dB	5.1dB	9.5GHz
UWB Antenna with truncated edges	2.8GHz – 13GHz	-48 dB	5.9dB	10.2GHz
Final UWB Antenna	2.7GHz – 13GHz	-52 dB	11.5 dB	10.3GHz
Band notched UWB Antenna	2.5GHz – 5.09GHz & 5.96GHz – 14GHz	-19 dB	6.5 dB	11.5GHz
	5.1 – 6.0 GHz (Notch band)	-3.5 dB	-3.8 dB	
Band notched UWB MIMO Antenna	2.8GHz – 5.09GHz & 6.01GHz – 14.8GHz	-21 dB	4.5 dB	12GHz
	5.15 - 6.0 GHz (Notch band)	-2.5 dB	-3.5 dB	

CONCLUSION

A compact 34 mm x 34 mm x 1.6 mm Band Notched UWB MIMO antenna with four symmetrical antenna elements placed orthogonal to each other is proposed. Partial ground and feedwidth variation improves the impedance matching bandwidth to 9.5GHz. The surface current distribution is affected and improved by corner truncated patch and slotted ground and bandwidth is improved to 9.8GHz. A band notch characteristics at WLAN (5.15GHz – 5.825GHz) is obtained by inserting a stub into the slot made in the feedline. To mitigate the multipath fading effect, a quad port MIMO antenna is designed and simulated for UWB frequency range of 2.5GHz - 15GHz with notch band at WLAN (5.15GHz - 6GHz). Return loss is less than -10dB in the entire operating frequency with a return loss of -3.5dB and VSWR of 5.2 at the notch band center frequency of 5.5GHz. Isolation parameters are S12 < -19dB, S13 < -22dB and S14 < -19dB in the acceptable range which indicates that the antenna elements are isolated from each other. The measured MIMO diversity parameters ECC, DG, and TARC are with in the acceptable range in the entire UWB (2.5GHz - 15GHz). The proposed quad port single band notched UWB MIMO antenna is suitable for MIMO applications in the UWB range.

FUTURE SCOPE

The proposed quad port Single band notched UWB MIMO antenna is designed to operate in the UWB range with band notching characteristics in the WLAN range of 5.15GHz - 5.825GHz. There are various other narrow band systems operating in the UWB range. Research work can be carried out to introduce band notching characteristics at other narrowband systems like WiMAX(3.3GHz – 3.6GHz), X-band Satellite Communication with uplink(7.25GHz – 7.75GHz) and downlink(7.9GHz – 8.4GHz) operating in the UWB range**.**

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