Design of Compact Planar Ultra-Wideband Antenna with Band-Notched Characteristics

A Thesis Submitted in partial fulfillment of the requirements for Degree of Bachelor of technology in Electronics and Communication engineering

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CERTIFICATE

This is to certify that the thesis entitled "**Design of Compact Planar Ultra-Wide band Antenna with Band-Notched Characteristics**" by **Mr. Debasish Pandav** and **Mr. Sabyasachi Sethi**, submitted to the **National Institute of Technology, Rourkela** in partial fulfilment of the requirements for the award of Bachelor of Technology Degree in **Electronics and Communication Engineering**, is a record of bonafide research work carried out by them in the department of Electronics and Communication Engineering, National Institute of Technology, Rourkela under my supervision. I believe that this thesis fulfils the partial requirement for awarding them the degree of Bachelor of Technology in Electronics and Communication Engineering. The results embodied in this thesis have not been submitted for the award of any other degree.

Date:

Place: Rourkela

(Prof. S. K. Behera)

ACKNOWLEDGEMENTS

We express our sincere gratitude and indebtedness to our project guide **Prof. S. K. Behera, S. Natarajamani** for their initiative in this field of research, for their valuable guidance, encouragement and affection for the successful completion of this work. Their sincere sympathies, thought provoking suggestions, timely advice and magnanimous attitude always encouraged us to carry out the present work firmly.

We express our gratefulness to our **Prof. S.K. Meher,** Head of the Department of Electronics and Communication Engineering, **NIT, Rourkela**, for providing us with the best facilities in the Department and his judicious suggestions.

We would also like to thank **Mr. K. Pandurangan**, Sales & Application Engineer, Computer Simulation Technology, India, for providing us with the student version of the **CST MICROWAVE STUDIO™ SUITE 2010.**

Last but not the least we would like to thank all our friends and well-wishers who were involved directly or indirectly in successful completion of the present work.

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ABSTRACT

Since the beginning of the human civilization mankind is trying to communicate with the others. It's the communication process i.e. the sharing of feelings, emotions and information has made us the greatest creation of God on this green earth. It all started with hand gestures, then sounds produced by vocal chords and gradually me moved to wired communication and now wireless communication. In wireless communication we mainly exploit the Electromagnetic Spectrum. Earlier systems were narrowband long range systems but in order to extend the use of available spectrum we are now using UWB (ultra-wide band) short range systems which require low power and these are built using inexpensive digital components. And Microstrip antenna is used for implementing UWB systems as it shows good broadband characteristics.

We propose a compact triple band notched CPW (Co-planar Waveguide) fed MSA (Microstrip Antenna) for UWB (Ultra-Wide Band) applications. The aforementioned antenna is designed using **CST MICROWAVE STUDIO^{TM} SUITE 2010**.

This band-notched antenna has rejection characteristics at 3.5 GHz (for Wi-MAX band-3.3 to 3.7 GHz), at 5.5 GHz (for WLAN 2 band-5.15 to 5.825 GHz) and at 8.2 GHz (for ITU band-8.025 GHz to 8.4 GHz).

First a Primitive antenna is taken. This antenna consists of a bevelled rectangular radiating patch and a CPW (co-planar waveguide) type feed structure. The essence of this design strategy is that three notching elements are embedded onto the primitive patch antenna to produce band-stop filtering function at those abovementioned frequencies. Notch elements are meticulously selected and embedded onto the antenna.

By etching two nested C-shaped slots in the radiating patch band rejection is achieved for Wi-MAX and WLAN 2. By etching two CSRRs (Complementary Split Ring Resonators) on the ground plane band rejection is achieved for ITU band.

Proper care has been taken while embedding the notch elements in order to minimize cross-coupling among the three notch elements.

The proposed Antennas were successfully designed, simulated and measured showing broadband features, stable radiation patterns and consistent gain. Measured results and graphs show validity of our suggested design.

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- ## Literature Review:

Qing-Xin Chu and Ying-Ying Yang [1] have done a thorough study on Compact planar ultra-wideband antenna and also proposed the use of nested C-shaped slots to produce band-notch characteristics in 3.4 GHz band and 5.5 GHz band in order to minimize the interference of the UWB antenna with Wi-MAX and WLAN 2 bands respectively. While etching the slots they have also discussed the mechanism by which the slots provide band-stop filter type response to the antenna performance. They have explained very clearly how the destructive interference for the surface currents makes the antenna non-responsive at those notch frequencies. They have also given the relationship between the notch frequency and the length of the slot to be etched. Also they have explained the dumbbell shape of E-plane and omnidirectional H-plane.

D.-O. Kim and C.-Y. Kim [9] has proposed a very novel strategy of integrating three notch elements on a primitive antenna to produce triple band-notch characteristics. They have also proposed a method to decrease the cross-coupling among notch elements. Optimized positioning of notch elements to achieve controllability of each rejection band is explained very clearly in this paper. The idea of using CSRRs (Complementary Split Ring Resonators) is described here. This paper also explores the importance of calculating return loss due to each element after embedding them on the primitive antenna. They have also instructed not to embed the notch elements blindly onto the patch antenna without taking into account the mutual coupling problem.

1. INTRODUCTION:

Since the FCC (Federal Communication Commission) approved the commercial use of UWB, the feasible design and implementation of UWB systems has aroused interest among many. An antenna designer has to face the challenges such as achieving radiation stability, reducing the antenna size and minimizing interference with other wireless systems. The antenna we are proposing here fulfils all such requirements.

1.1. What is UWB?

- UWB (Ultra Wide-Band) is a radio communication technology that uses very low energy pulses & it is intended for short-range-cum-high-bandwidth communications by using a huge chunk of the radio spectrum (in GHz Range).
- UWB communications transmit in a way that doesn't interfere with other traditional narrowband and continuous carrier wave systems operating in the same frequency band.
- And UWB is a Very High-speed alternative to existing wireless technologies such as WLAN, HiperLAN.
- A February 14, 2002 Report and Order by the FCC (Federal Communication Commission) authorized the unlicensed use of UWB in the range of 3.1 to 10.6 GHz for commercial applications.
- The approved FCC power spectral density emission limit for UWB emitters operating in the UWB band is -41.3dBm/MHz. This is called Part 15 limit the same limit that applies to unintentional emitters in the UWB band.
- UWB RF technology transmits Binary data (0/1) over a very wide spectrum of frequencies using low energy and extremely short duration pulses (in the order of Pico-seconds).
- In a Multi-user environment to minimize interference each device is given a unique PN code (Pseudo-random Noise).And a receiver operating with the desired PN code can decode the transmission.

UWB Spectrum:-

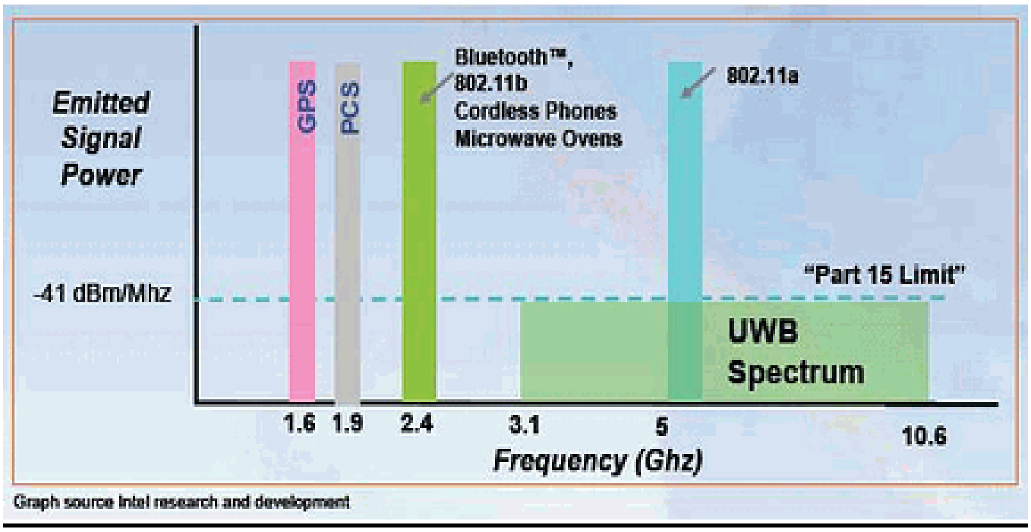


Fig.1.1: Comparison of various communication standards.

Advantages of UWB Technology:-

- **Capacity-**

  It can achieve very high data rate (can reach up to 500 Mbps).

  $$C = B.\mathrm{Log}_2\,(1+SNR) \qquad (1)$$

  Where C=Channel Capacity.

  B=Bandwidth of Channel.

  Its bandwidth is from 3.1 GHz to 10.6 GHz and each channel is of more than 500 MHz BW.

- **Low power & low cost-**

  No need of modulation. Un-modulated baseband pulses of very short duration are sent in this communication technology, that's why it is known as a "Carrier free Impulse Baseband Radio". It is an all-Digital System not requiring any kind of analog components such Mixers/Balanced Modulators for signal modulation.

  It needs very small Transmitter power for its transmission. And Power is in microwatt range.

- **Fading Robustness-**

  Wideband nature of the signal helps it avoiding the problem of time varying amplitude fluctuations.

  It is also immune to Multipath Delays (introduced due to non-LOS(line of sight) communication where various version of same signal appear at the receiver which have undergone a variety of diffraction, reflection, scattering effects) as time delay introduced is generally more than the signal duration.

- **Flexibility-**

  It can dynamically trade-off throughput for distance.

- **Short Range-**

  Its normal range of operation is within 10 m, so its power requirement is low and interference with other short range devices is less. It comes under WPAN (Wireless Personal Area Network) protocol.

- **Security Aspects-**

  It behaves as a wideband noise source for other NB (Narrow Band) systems operating in that frequency range; but it doesn't affect them because of its low signal power. It only increases the SNR requirement of those systems.

  By using PN (Pseudo Random) codes UWB system can be made undetectable for hostile receivers and can be protected form Jamming.

- **Multiple Access-**

  Various Modulation techniques can be employed.

  For ex- a) PPM (Pulse Position Modulation).

  b) BPSK (Binary Phase Shift Keying).

  c) Bi-Orthogonal.

  d) PAM (Pulse Amplitude Modulation)

  e) OOK (On-Off Keying).

For Multiple access we can use

a) TH-UWB (Time Hopping)

b) DS-UWB (Direct Sequence)

1.2. Microstrip Antenna (MSA)

What is an Antenna?

Antenna is a transducer employed to transmit or receive electromagnetic waves. Antenna is the transitional structure used between free-space and the energy guiding device. And guiding device is the device used for electromagnetic energy transportation from the transmitting source to the antenna, or from the antenna to the receiver.

Microstrip antenna

- This is also known as Patch Antenna because of its structure. A MSA (Micro Strip Antenna) consists of a dielectric substrate having a metallic radiating part on one side and a metallic ground plane on the other.
- Common microstrip antenna shapes are square, rectangular, circular and elliptical, because of easy fabrication and easy analysis; but any continuous shape can be used. Some microstrip antennas do not use a dielectric substrate and instead they use a metal patch mounted above a ground plane using dielectric spacers; the resulting structure is less rugged but has a wider bandwidth.
- Such antennas have a very low profile, are mechanically rugged and conformable to planar and non-planar surfaces, they are often mounted on the exterior of aircrafts, or are used in mobile radio communications devices.
- Microstrip antennas are also relatively cheap to manufacture using modern Printed-Circuit type technology. They are usually employed at UHF and higher frequencies because the size of the antenna is directly related to the wavelength at the resonant frequency.

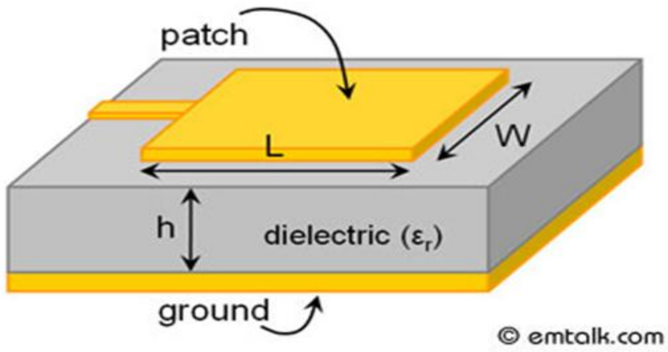


Fig.1.2. Rectangular Patch Antenna.

Advantages of MSA

- Low Profile planar configuration, light weight and have small volume.
- Conformable to various host surfaces (planar/non-planar).
- Easy to install and inexpensive to manufacture using Printed-Circuit technology.

- Flexible and versatile in terms of pattern, polarization, resonant frequency & impedance, as these parameters can be varied using loads (such as Pins or Varactor Diodes) between the patch and the ground plane.
- Feed lines and matching networks can be fabricated simultaneously with the antenna.
- Allow both Linear Polarization and Circular Polarization.
- Allow Dual-band and/or Dual notch operations.
- Arrays can be formed in order to get high scan and large range.

Disadvantages of MSA

- Very narrow bandwidth.
- Spurious radiation (surface waves).
- Need quality substrates ($\tan\delta<0.002$)
- Difficult to achieve polarization purity.
- Lower Power handling capacity.
- Large ohmic loss in the feed structures.
- High Q-factor (sometimes more than 100).
- Low Efficiency.

1.3.Feeding Techniques:

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories-

a) Contacting.

b) 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/Coaxial Cable.

In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch such as aperture coupling and proximity coupling.

1.3.1 Microstrip Line Feed:

In this type of feed technique, a conducting strip is connected directly to the edge of the Micro-strip patch. The conducting strip is made smaller in width as compared to the patch. Advantage is that the feed can be etched on the same substrate to provide a planar structure.

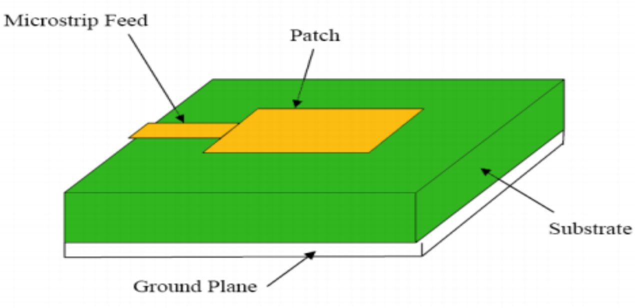


Fig.1.3.Microstrip line feed

Actually this kind of feeding has very high resonant input impedance. The Resonant input impedance can be decreased by using an inset feed recessed by some distance from the input slot. Impedance matching leads to less reflection loss at the feed-slot junction. However, the inset feed introduces a physical notch and this notch introduces junction capacitance and this junction can affect the resonant frequency.

1.3.2 Co-axial feed:

The Coaxial feed or Probe feed is also used for feeding Micro-strip antennas. The inner conductor of the coaxial connector extends through the dielectric and is attached to the radiating patch, while the outer conductor is connected to the ground plane.

The main advantage is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This is easy to fabricate and has low spurious radiation.

However, the main disadvantage is that it provides narrow bandwidth and it is difficult to model since a hole has to be made in the substrate and the connector bulges outside the ground plane.

For thick dielectric substrates, which provide broad bandwidth, the micro-strip line feed and the coaxial feed suffer from numerous disadvantages. Both of them possess inherent asymmetries and that leads to the generation of higher order modes and cross polarization.

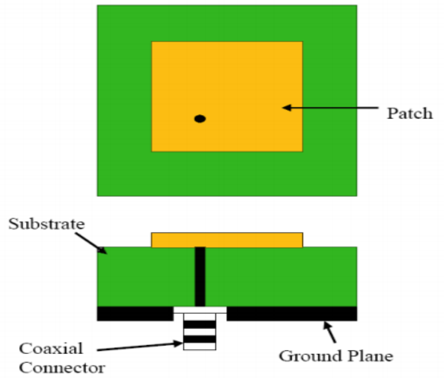


Fig.1.4. Probe fed Rectangular Micro-strip Patch Antenna.

The non-contacting feed methods can solve the problems faced by contacting feed methods.

1.3.3. Aperture Coupled Feed:

The aperture coupling method is the most difficult one to fabricate. However, it is very easier to model and has little spurious radiation problem. In this method the radiating patch and the micro-strip feed line are separated by the common ground plane. Coupling of energy between the patch and the feed line is made through a slot/ aperture in the ground plane.

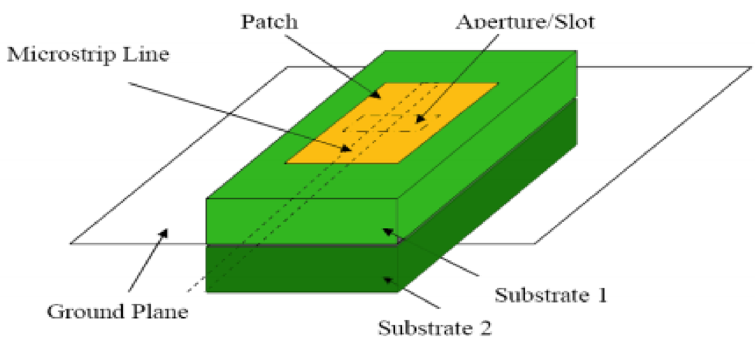


Fig.1.5.Aperture Coupled Feed

The coupling aperture is usually made under the patch, leading to lower cross-polarization. The amount of energy coupling from the feed line to the patch depends on the shape, size and location of the aperture. As the ground plane separates the patch and the feed, spurious radiation is minimized. Generally, a thick, low dielectric constant material is used for the top substrate and a high dielectric material is used for bottom substrate to optimize radiation from the patch.

The main disadvantage of this feed method is that it is difficult to fabricate due to presence of multiple layers, which also increases the antenna thickness. This feeding scheme also produces narrow bandwidth.

1.3.4 Proximity Coupled Feed:

This feed technique employs electromagnetic coupling scheme.

Two dielectric substrates are used and the feed line is situated between the two substrates and the radiating patch is on top surface of the upper substrate.

The main advantage is that it minimizes spurious feed radiation and provides very high bandwidth (as high as 13%), due to overall increase in the thickness of the antenna. This method provides choices between two different dielectric media, one for the patch and one for the feed line; so it provides higher degree of freedom to optimize the individual performances.

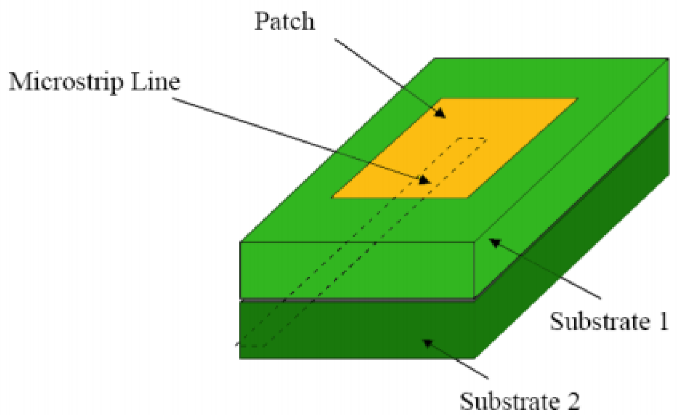


Fig.1.6.Proximity Coupled Feed

The major disadvantage of this feeding method is that it is difficult to manufacture because of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the microstrip antenna.

1.3. Parametric Study of Rectangular Patch Antenna:

The RMSA (Rectangular Micro-strip Antenna) is the most widely used patch antenna. And it is very easy to analyze using both the Transmission-line model and the Cavity model because of its thin substrate.

1.4.1. Transmission-line Model:

It is easiest method of analysis; but it yields the least accurate results and it is not so versatile.

A RMSA can be represented as an array of two radiating slots each having width=W and height=h and separated by distance=L.

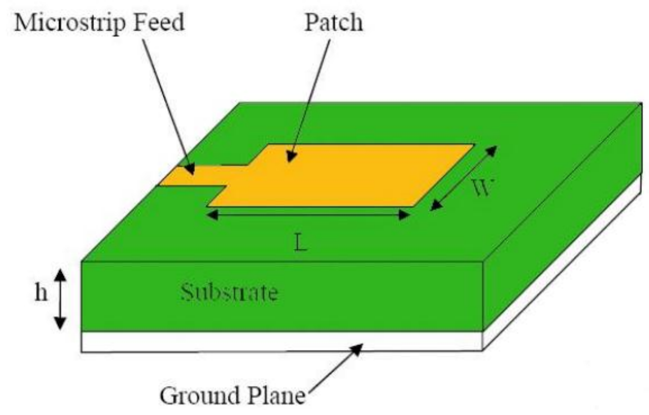


Fig.1.7. Rectangular patch antenna.

1.4.2. Fringing Effects in RMSA:

Because of finite dimensions along the length and width, the fields at the edges of the patch antenna undergo fringing effects.

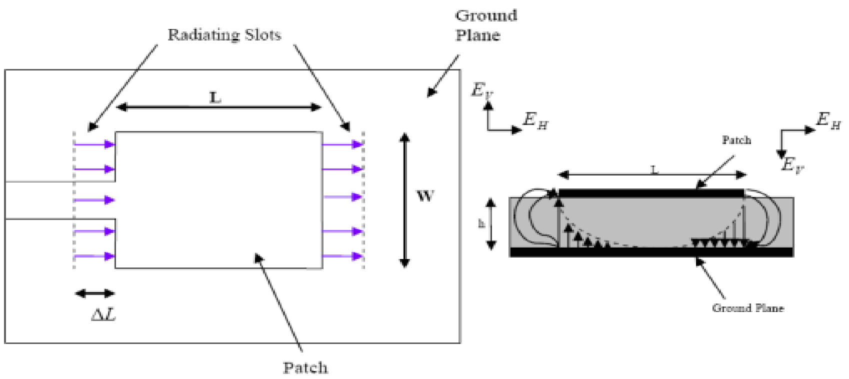


Fig.1.8. Top view and the side view of a patch antenna.

The fringing is illustrated here in the above picture. The amount of fringing is dependent on a) Dimensions of the patch.

b) Height of substrate.

Fringing affects the resonant frequency of the antenna.

Fringing makes the micro-strip line wider and longer electrically compared to its actual physical dimensions. As the fields pass through both air and dielectric we calculate the *Effective Dielectric Constant* (ε_{reff}) to account for fringing.

$$\underline{W/h > 1}$$

$$\epsilon_{\text{reff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{2}$$

Where,

ε_{reff} = Effective dielectric constant.

ε_r = Dielectric constant of substrate.

h = Height of dielectric substrate.

W = Width of the patch.

The ε_{reff} (Effective dielectric constant) has values in the range of $1< \varepsilon_{reff}< \varepsilon_r$. ε_{reff} is also a function of frequency. As the frequency of operation increases, most of the electric field lines start to accumulate in the substrate. And the patch behaves like a homogenous line of one dielectric, and ε_{reff} value approaches nearer to ε_r.

1.4.3. Effective Length, Effective width, Resonant Frequency:

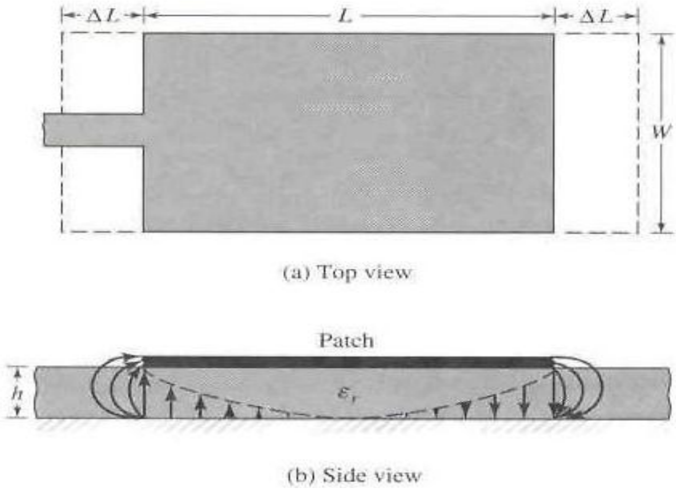


Fig.1.9. Actual and effective length of rectangular patch.

Fringing effects leads to lengthening of L and widening of W. The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is a function of ε_{reff} and W/h (Width-to-Height Ratio). It is given as:

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{3}$$

Now the effective length of the patch becomes:

$$L_{eff} = L + 2\Delta L \tag{4}$$

For a given resonant frequency the effective length is given by:

$$L_{eff} = \frac{c}{2 f_o \sqrt{\varepsilon_{reff}}} \tag{5}$$

The resonant frequency for any rectangular micro-strip patch is given as:

$$f_o = \frac{c}{2\sqrt{\varepsilon_{reff}}} \left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2 \right]^{\frac{1}{2}} \tag{6}$$

Where m,n are the modes for L and W respectively.

For efficient radiation the width (W) is given by:

$$W = \frac{c}{2 f_o \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{7}$$

Where f_0 = Resonant frequency.

C =speed of light in free-space.

1.4.4. Bandwidth:

Bandwidth increases as the substrate thickness (h) increases (the bandwidth is directly proportional to h if surface-wave losses are ignored). However, increasing the substrate thickness (h) decreases the Q (Quality factor) of the cavity, which increases spurious radiation from the feed, as well as excites higher-order modes in the patch cavity. And higher order modes lead to cross-polarization. Also, the patch becomes difficult to match as the substrate thickness increases beyond a particular point (typically about 0.05 λ0). However, in recent years considerable effort has been done to improve the bandwidth of the micro-strip antenna by using alternative feeding schemes.

The aperture-coupled feed is one method that overcomes the problem of probe inductance, but it increases complexity. Decreasing the substrate permittivity also increases the bandwidth (BW) of the micro-strip antenna. However, this makes the patch larger.

By using a combination of aperture-coupled feeding and a low-permittivity foam substrate, bandwidths exceeding 25% have been obtained. The use of stacked patches can also be used to increase bandwidth even further.

Formula for the bandwidth (defined by VSWR < 2.0) is,

$$BW = \frac{1}{\sqrt{2}}\left[\tan\delta_d + \left(\frac{R_s}{\pi\eta_0\mu_r}\right)\left(\frac{1}{h/\lambda_0}\right) + \left(\frac{16}{3}\right)\left(\frac{pc_1}{\varepsilon_r}\right)\left(\frac{h}{\lambda_0}\right)\left(\frac{W}{L}\right)\left(\frac{1}{e_r^{sw}}\right)\right] \tag{8}$$

1.4.5. Resonant Frequency:

The resonance frequency for the TM (0, 1, 0) mode is given by,

$$f_0 = \frac{c}{2L_e\sqrt{\varepsilon_r}} \tag{9}$$

Where, c is the speed of light in vacuum.

And length Le (Effective Length) is chosen as

$$L_e = L + 2\Delta L \tag{10}$$

Formula for the extended length due to fringing effect is given as,

$$\frac{\Delta L}{h} = 0.412\left(\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}\right) \tag{11}$$

Where,

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{W}\right)^{-1/2} \tag{12}$$

CHAPTER 2

- **ANTENNA DESIGN**
  - **Primitive Antenna**
  - **Antenna with C-slot (for band-notch at 3.5 GHz)**
  - **Antenna with C-slot (for band-notch at 5.5 GHz)**
  - **Antenna with two CSRRs**
  - **Antenna with Triple band-notch features**

2. ANTENNA DESIGN:

The geometry of the antennas in this section was decided by the parametric study of each element in the software. The detailed parametric study is discussed in the section 3.2. The band notches are introduced in order to stop the function of the antenna in that particular frequency range. By this the interference between the UWB system and the narrow band system is reduced to a great extent. Introduction of the band notches helps us to avoid the use of the band stop filters and hence reducing the cost and complexity of the antenna. Now-a-days demand is for miniaturized technology and MSA helps us in achieving that.

2.1. Primitive antenna:

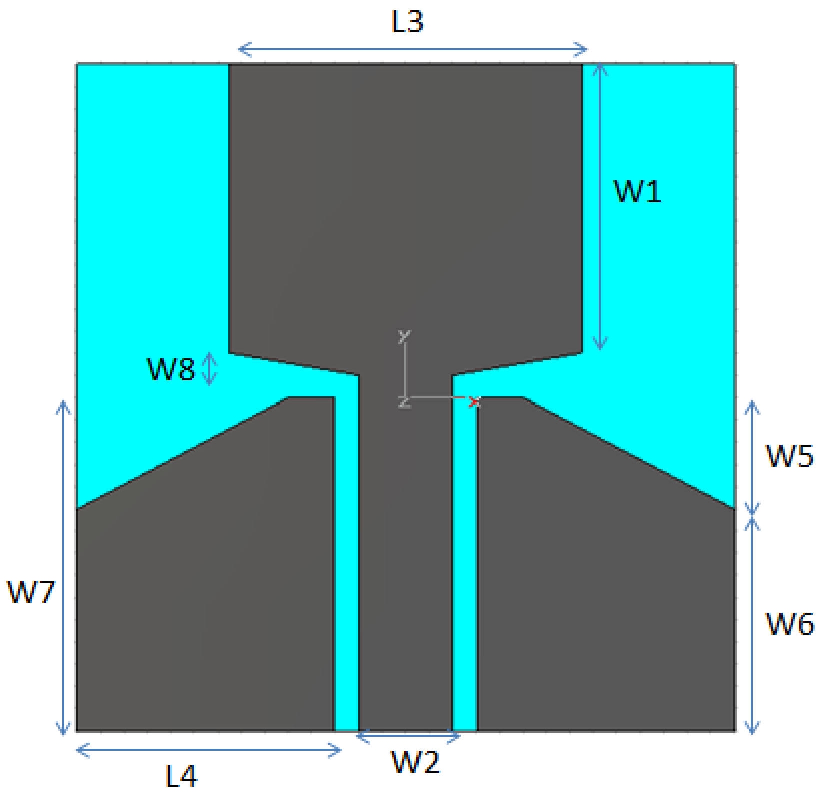


Fig.2.1. Geometry of CPW fed planar antenna.

Antenna Description:

Parameters	Dimensions
W1	14 mm
W2	3 mm
W5	5 mm
W6	10 mm

W7	15 mm
W8	1 mm
L3	15 mm
L4	11 mm

Table.2.1. measurements of the primitive antenna (without any slots)

Primitive antenna consists of a rectangular patch (trimmed) and trimmed ground plane to enhance the antenna's broadband performance and also it this arrangement increases the flow of surface current through the feed-line and concentrates the surface current around the bottom of the radiating patch.

First a rectangular patch is designed using CST microwave Studio^{TM} suite 2010 and then it is trimmed by removing triangular shaped parts using the extrude feature. Triangular shaped parts are also removed from the rectangular shaped ground plane in order to smooth the surface current flow. Radiating patch is made using PEC (Perfect Electrical Conductor) material.

Dielectric material used here has relative permittivity= 4.4

Thickness of substrate= 1.6 mm.

Length of substrate= 28 mm.

Width of substrate= 30 mm.

2.2. Antenna with C-slot (for band-notch at 3.5 GHz)

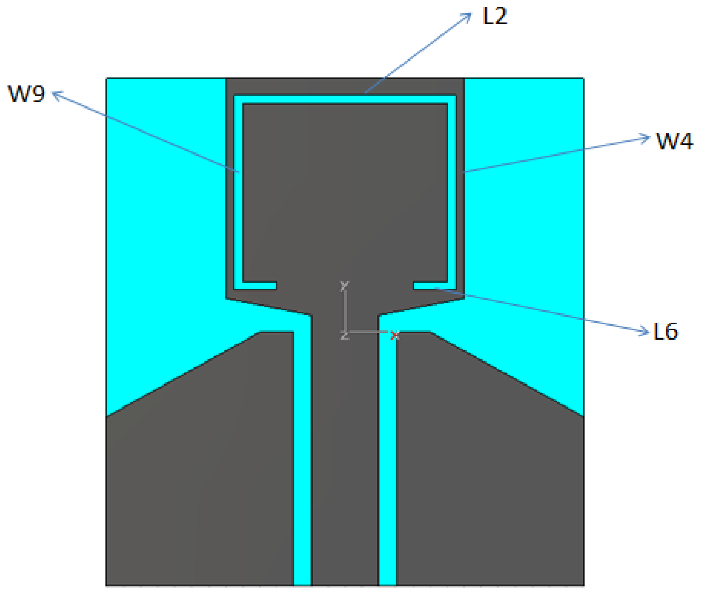


Fig.2. 2. Geometry of antenna with C-slot to produce band-notch at 3.5 GHz.

Antenna Description:

Parameters	Dimensions
L2	13 mm
L6	2.5 mm
W4	11.5 mm
W9	11.5 mm
Thickness of slot	0.5 mm

Table.2.2. measurements of the C-shaped slot (band notch at 3.5 GHz)

FCC (Federal Communication Commission) approved and authorized the 3.1 GHz to 10.6 GHz band as the UWB (Ultra-wide Band). But Wi-MAX (Worldwide Interoperability for Microwave Access) operates in the range of 3.3 GHz to 3.7 GHz and interferes with UWB devices. So instead of using a band-stop filter at the receiver antenna we have etched a C-shaped slot on the radiating patch in order to facilitate band-rejection facility around 3.5 GHz, so that the interference is minimized.

2.3. Antenna with C-slot (for band-notch at 5.5 GHz)

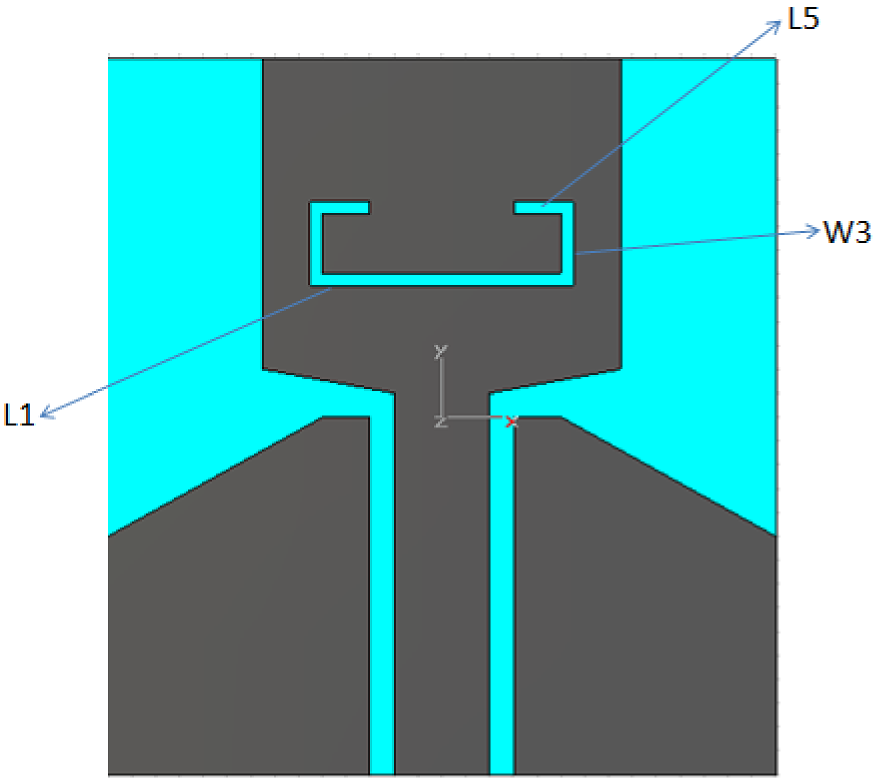


Fig.2.3. Geometry of antenna with C-slot to produce band-notch at 5.5 GHz.

Antenna Description:

Parameters	Dimensions
L1	11 mm
L5	2 mm
W3	7.5 mm
Thickness of the slot	0.5 mm

Table.2.3. measurements of the C-shaped slot (band notch at 5.5 GHz)

WLAN 2 (Wireless Local Area Network 2- 5.15 GHz to 5.825 GHz) interferes with the UWB systems. In order to minimize the interference we have etched a C-shaped slot on the radiating patch to create a notch around 5.5 GHz.

2.4. Antenna with two CSRRs:

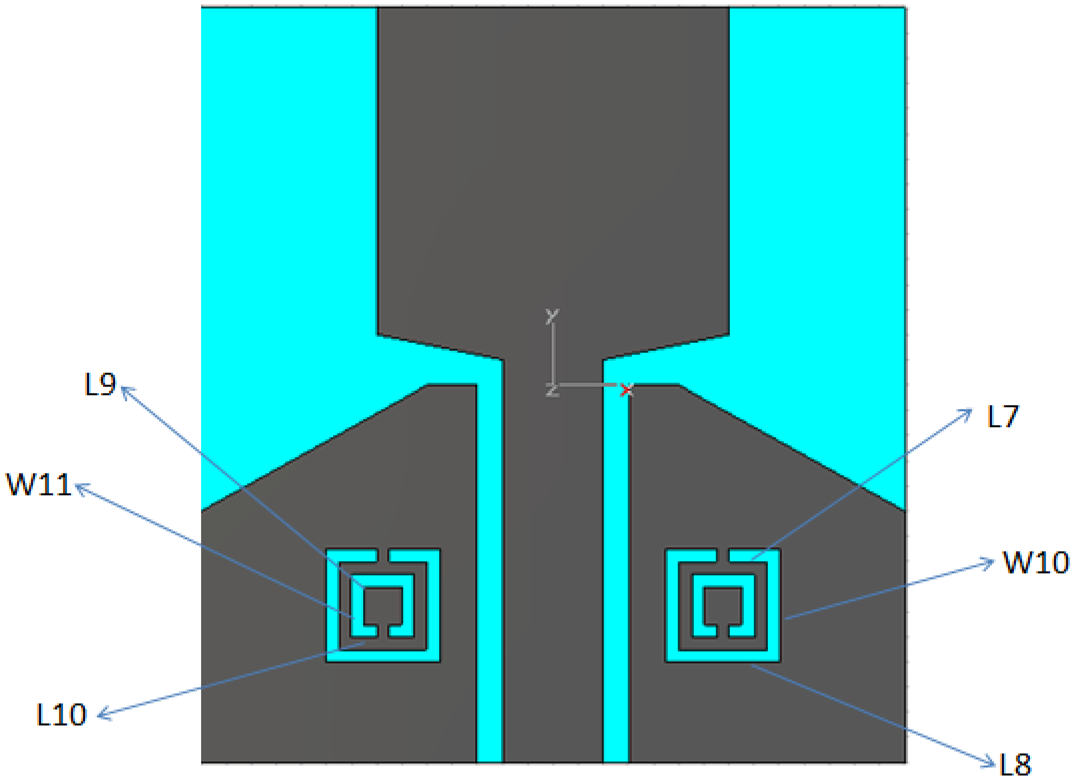


Fig.2.4. Geometry of antenna with a pair of CSRRs (notch at 8 GHz)

Antenna Description:

Parameters	Dimensions
L8	4.5 mm
L7	1.5 mm
L9	2.5 mm
L10	0.5 mm
W10	4.5 mm
W11	2 mm
Thickness of the slot	0.5 mm

Table.2.4. measurements of the 2 CSRRs (Complementary Split Ring Resonator) providing us with a band notch at 8GHz.

ITU (international telecommunication union) band operates in the range of 8.025 GHz to 8.4 GHz and possess a threat to UWB systems. By etching 2 CSRRs (complementary split ring resonators) on the ground plane we have created the required band notch in the ITU band.

2.5. Antenna with Triple band-notch features:

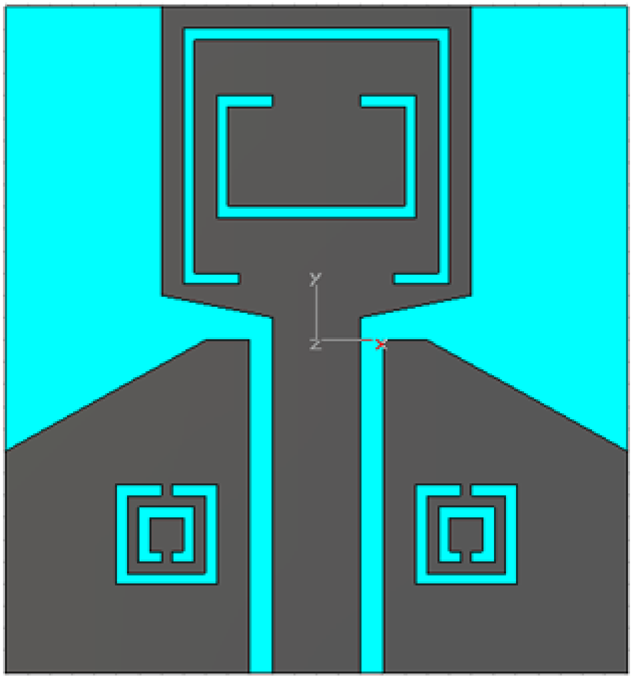


Fig.2.5. Geometry of antenna with triple band notch.

Antenna Description:

Producing single band notch feature in an antenna is easy, because one needs to embed the notch element in the radiating patch. Even designing dual band notch characteristics is easy. But when it comes to triple band notch or any higher band notch then cross coupling among the notch elements creates the problem and controlling the elements really depends upon the ingenuity of the antenna designer.

To achieve band notch controllability we have taken following steps:

1. Assigning a distinct rejection band for each notching element.
2. Controlling the shape of each element and their optimized positions in order to minimize coupling.
3. Combination of each notch element on the primitive UWB antenna is aimed for providing triple band rejection function at Wi-MAX (3.3- 3.7 GHz), WLAN 2 (5.15-5.825 GHz) and ITU 8GHz (8.025-8.4 GHz).

Design Details:

Measurements of the primitive antenna and all the 3 slots:

Parameters	Dimensions
W1	14 mm
W2	3 mm
W3	7.5 mm
W4	11.5 mm
W5	5 mm
W6	10 mm
W7	15 mm
W8	1 mm
W9	11.5 mm
W10	4.5 mm
W11	2 mm
L1	11 mm
L2	13 mm

L3	15 mm
L4	11 mm
L5	2 mm
L6	2.5 mm
L7	1.5 mm
L8	4.5 mm
L9	2.5 mm
L10	0.5 mm
Thickness of the slot	0.5 mm

Table.2.5. the above table gives us the measurements of the antenna as well as the measurements of the 2 C-shaped slots and a pair of CSRRs.

The band notch operations are achieved by etching 2 C-shaped slot in the rectangular metal radiating patch and by etching a pair of CSRRs in the ground plane (as shown in the Fig.2.5.). It is found that by adjusting the total length of the C-shaped slot to be approximately half wavelength of the desired notched frequency, a destructive interference can take place, causing the antenna to be non responsive at that particular frequency. It is very easy to tune the notch centre frequency with the change in the total length of the C-shaped slot. More experiments were carried out on the length of the C-shaped slot using the **CST MICROWAVE STUDIO^{TM} SUITE 2010**.

CHAPTER 3

- **RESULTS AND DISCUSSION**
  - **VSWR vs. Frequency Graphs**
  - **Parametric Study**
  - **Surface Current Patterns**
  - **Radiation Pattern**
    - ✓ **E-Plane Radiation Patterns**
    - ✓ **H-Plane Radiation Patterns**
  - **Gain vs. Frequency Graphs**

3. RESULTS & DISCUSSIONS

The antenna designs in the previous section were simulated in the CST Microwave Studio TM suite 2010 in order to get the following radiation parameters.

Mainly we have considered a) VSWR vs. Frequency and b) Gain vs. Frequency to judge the performance of the antennas.

3.1 VSWR vs. FREQUENCY GRAPHS:

(a) For Primitive Antenna:

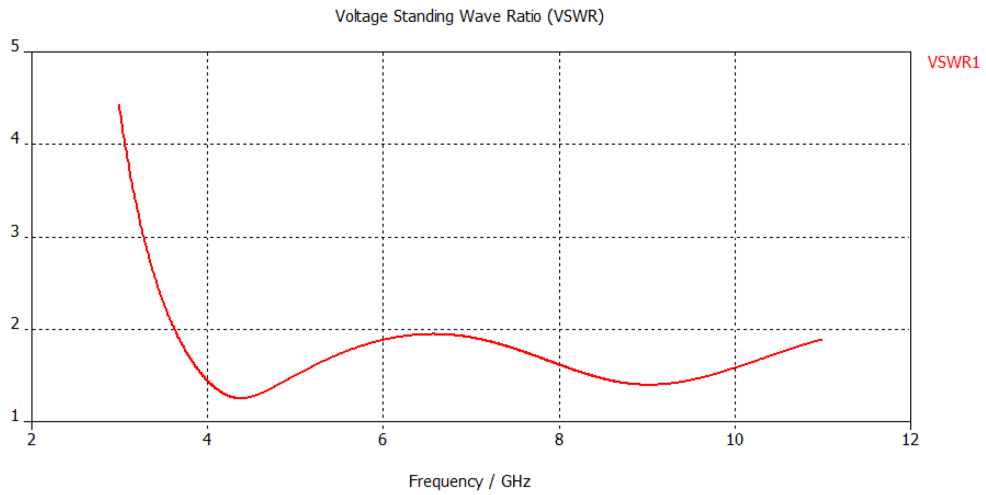


Fig.3.1. VSWR vs. frequency graph for the primitive antenna

The VSWR vs. Frequency graph of the primitive antenna is showing that the VSWR value lies below 2.

(b) For Antenna with C-slot (notch at 3.5 GHz):

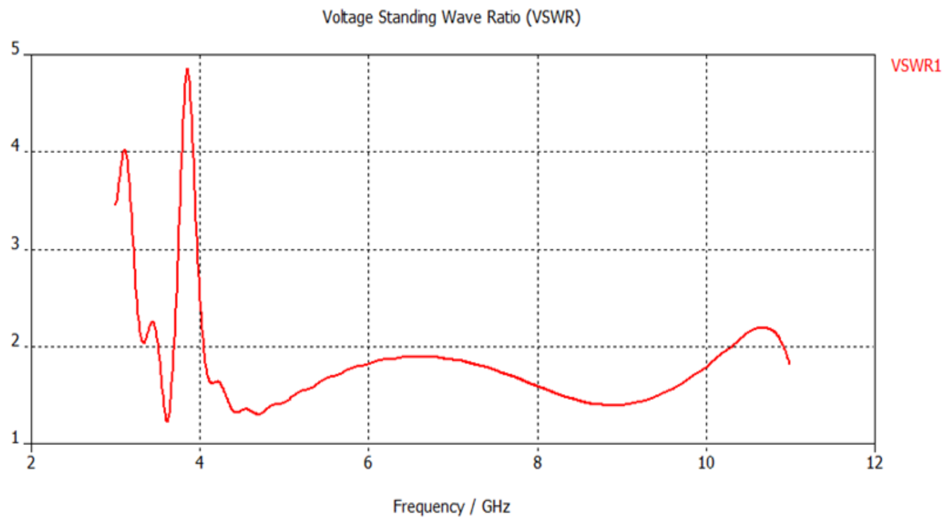


Fig.3.2. VSWR vs. frequency graph for the antenna with band notch at 3.5 GHz.

This graph shows the band notch in the frequency range of 3.3- 3.8 GHz that is caused due to the C-shaped slot in the radiating patch (Fig.2.2).

(C) Antenna with C-slot (notch at 5.5 GHz):

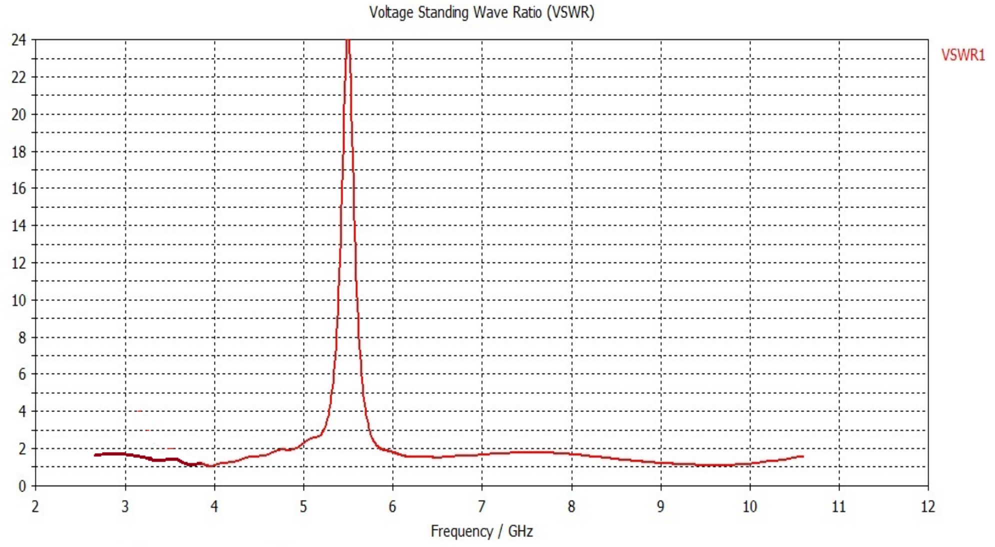


Fig.3.3. VSWR vs frequency graph for the antenna with band notch at 5.5 GHz

This graph gives us the idea about the band notch caused due to the C-shaped slot in the frequency range of 5-6 GHz.

(D) Antenna with 2- CSRRs (notch at 8 GHz):

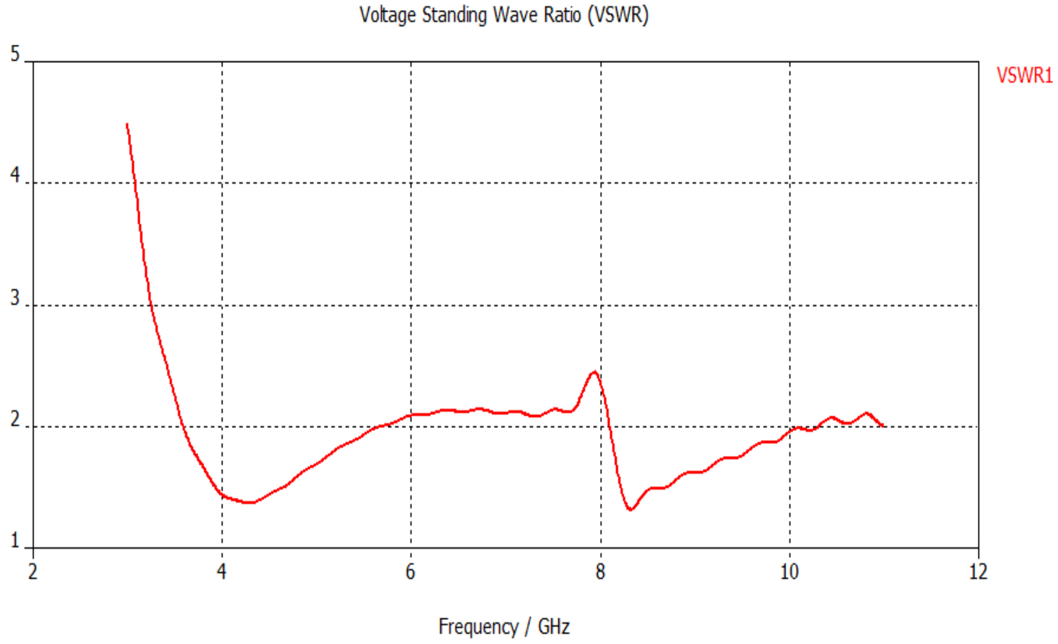


Fig.3.4. VSWR vs frequency graph for the antenna with band notch at 8 GHz.

This VSWR vs. Frequency graph shows the band notch caused by the pair of CSRRs in the frequency range of 8 GHz - 8.4 GHz.

(E) Triple band-notch Antenna:

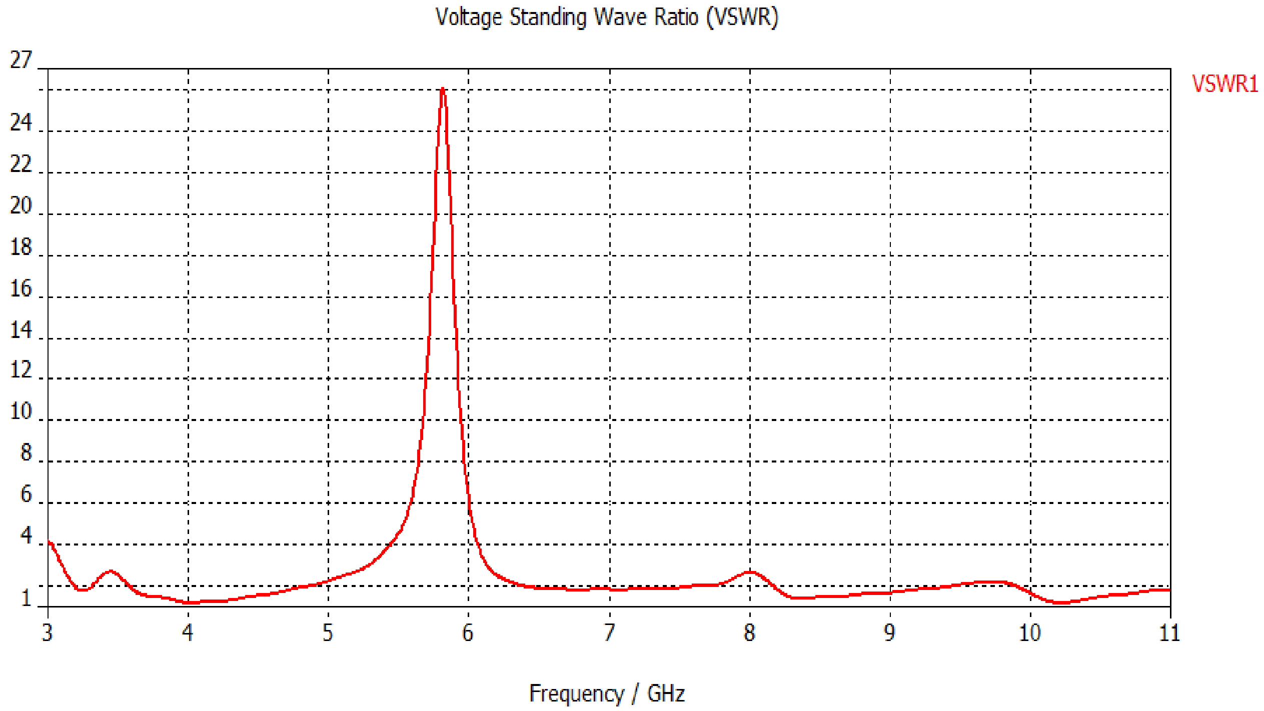


Fig.3.5. VSWR vs. frequency graph for the triple band notch antenna.

This VSWR vs. frequency graph belongs to the triple band notch antenna, with the band notches at 3.5 GHz, 5.5 GHz and 8 GHz. The band notches at the frequency 3.5 GHz and 8 GHz is small because of the cross coupling caused due to the integration of all the 3 slots at a time in one antenna.

3.2 PARAMETRIC STUDY:

(A) Effect of width variation of the radiating patch:

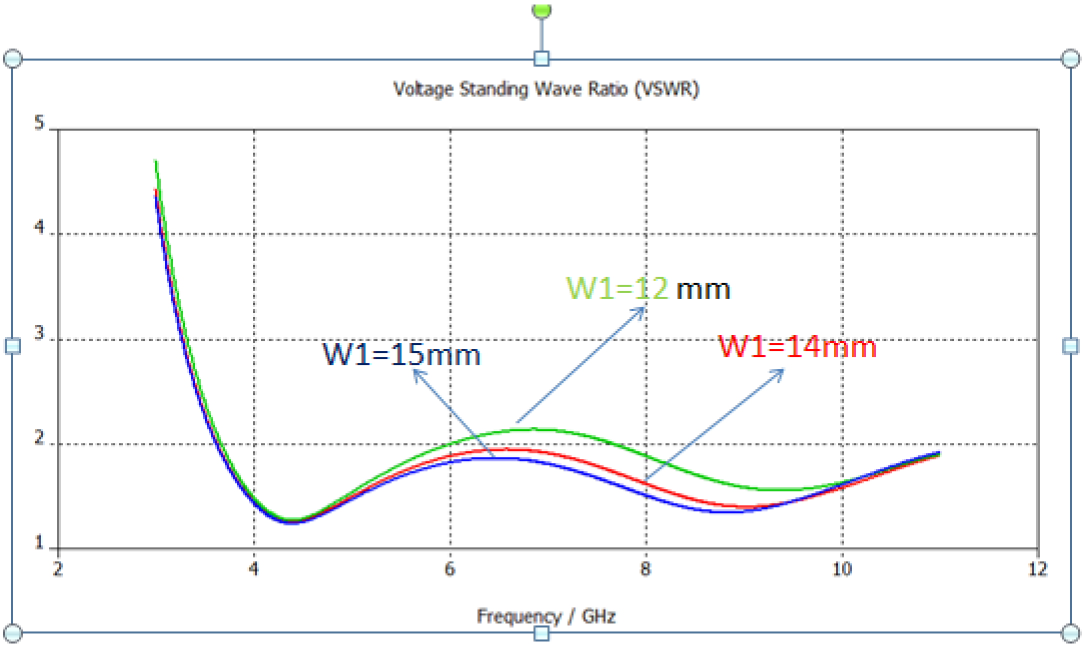


Fig.3.6. VSWR graph showing the Effect of width variation of the radiating patch.

After the parametric study of the width of the radiating patch we find that **W1=15mm** is the optimum condition for the antenna to work properly.

(B) Effect of width variation of the feed-line:

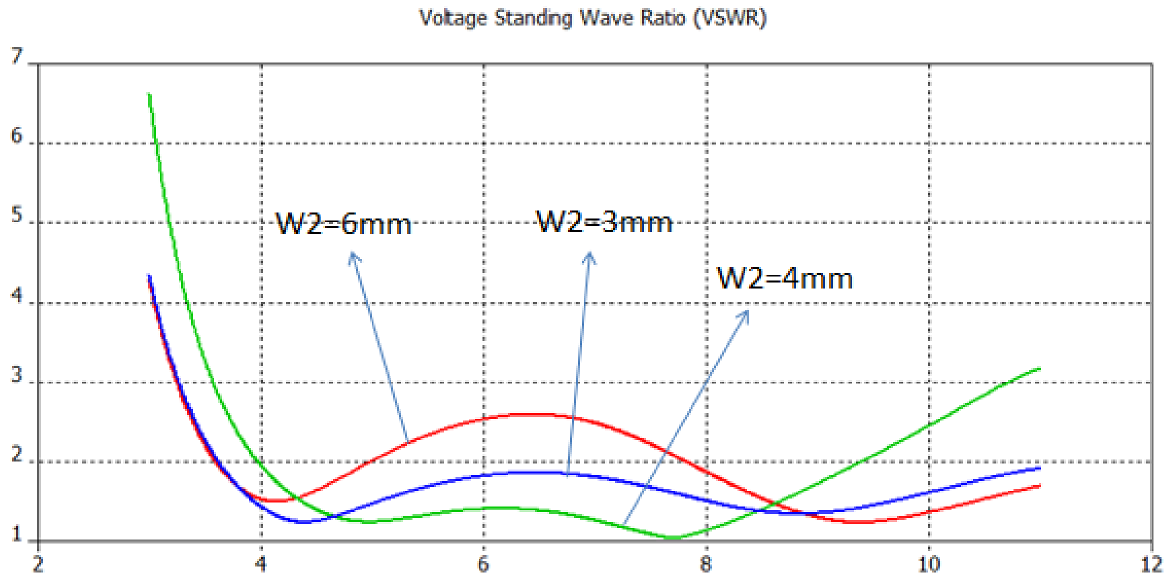


Fig.3.7. VSWR graph showing the effect on Feed-line width variation.

By increasing the width of the feed line the bandwidth decreases, so the optimum condition for the width of the feed line is **W2= 3mm.**

(C) Effect of variation of width of the C-shaped slot for 5.5 GHz:

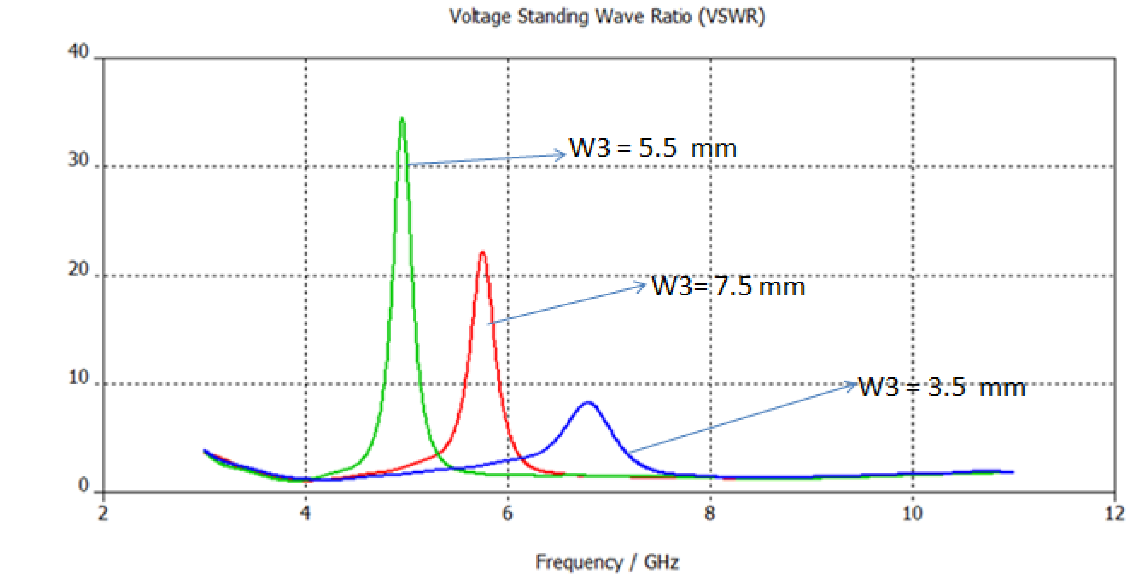


Fig.3.8. VSWR graph showing the effect of variation of width of the C-shaped slot for 5.5 GHz.

In order to get a band notch in the frequency range of 5-6 GHz we need to maintain the width of the C-shaped slot in such a way that we get a band notch in the frequency range of 5.5 GHz – 5.8GHz. So the optimum condition for the width of the C-shaped slot is **W3= 7.5mm.**

(D) Effect of length change of the C-shaped slot 5.5 GHz:

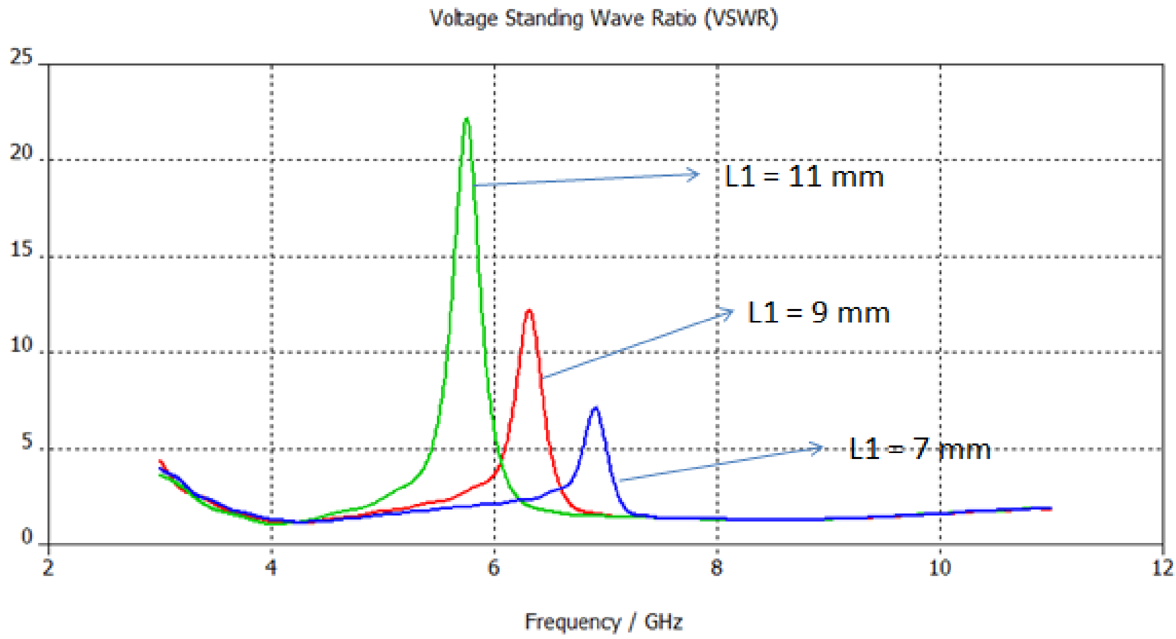


Fig.3.9. VSWR graph showing the effect of length change of the C-shaped slot 5.5 GHz.

The length is increased so that the frequency range decreases, as a result the band notch is achieved in the frequency range of 5.5 Hz – 6 GHz. Therefore the optimum condition for the length of the C-shaped slot is **L1 = 11 mm.**

(E) Effect of width change of the C-shaped slot at 3.5 GHz:

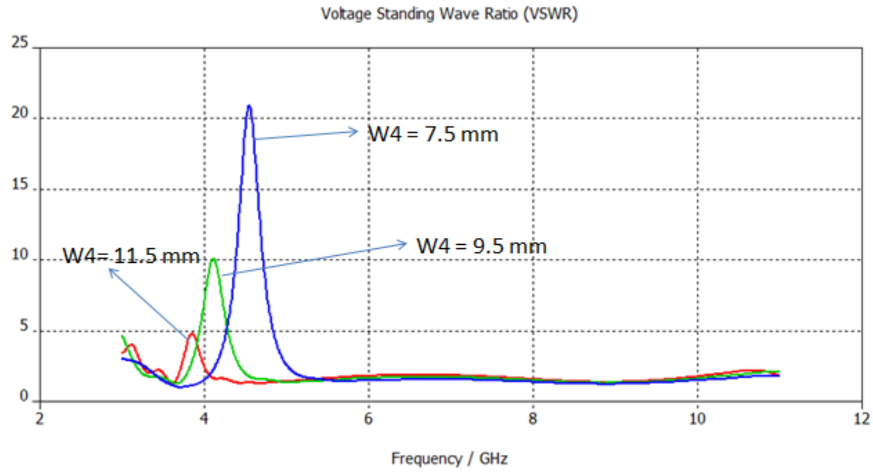


Fig.3.10. VSWR graph showing the Effect of width variation of the C-shaped slot i.e. used for the band notch at 3.5 GHz.

When the width of the C-shaped slot is varied we find a band notch at the frequency of 3.5 GHz and hence the optimum condition of the width of the C-shaped slot is **W4 = 11.5 mm.**

(F) Effect of Length variation of the c shaped slot for 3.5 GHz:

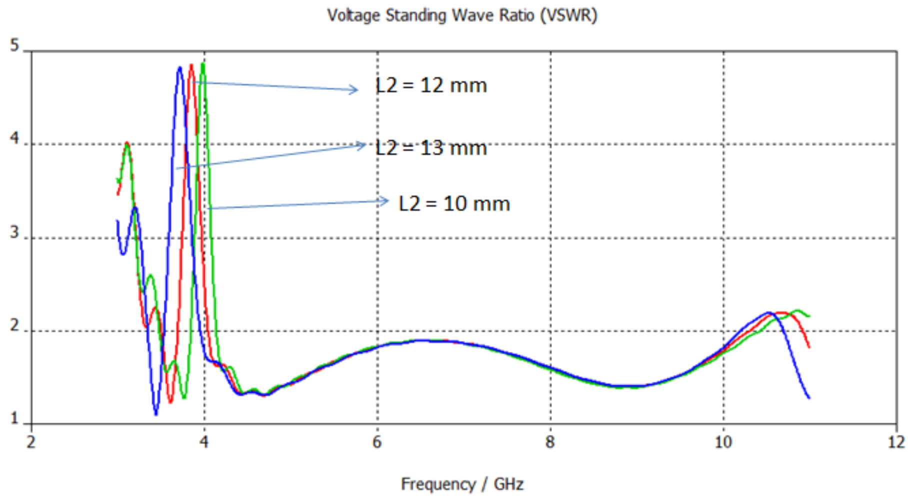


Fig.3.11. VSWR graph showing the effect of length variation of the c shaped slot for 3.5 GHz.

Same is the case for the length of the C-Shaped slot, after varying the length of the slot we find a band notch in the frequency range of 3.3 GHz- 3.8 GHz. Therefore the optimum condition for the length of the C-shaped slot is **L2 = 13 mm.**

3.3 SURFACE CURRENT DISTRIBUTION:

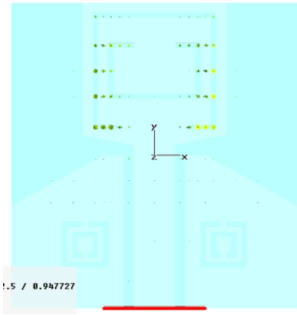
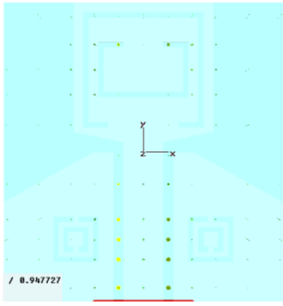
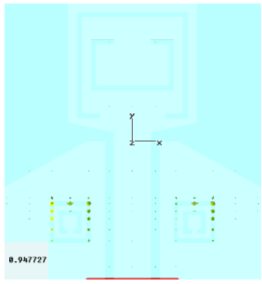
a. 
b. 
c. 

Fig.3.12. a. Surface current for single band-notch antenna at 3.5 Ghz.

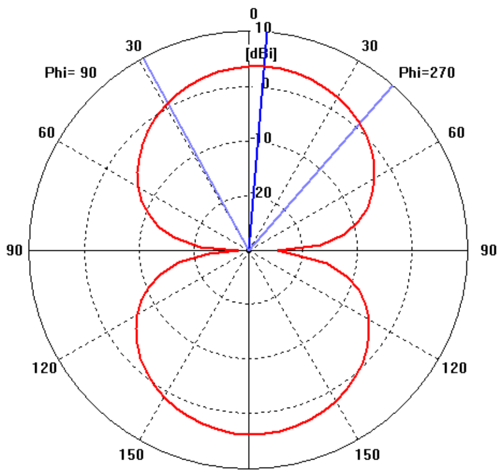
b. Surface current for single band-notch antenna at 5.5 Ghz.

c. Surface current for single band-notch antenna at 8 Ghz.

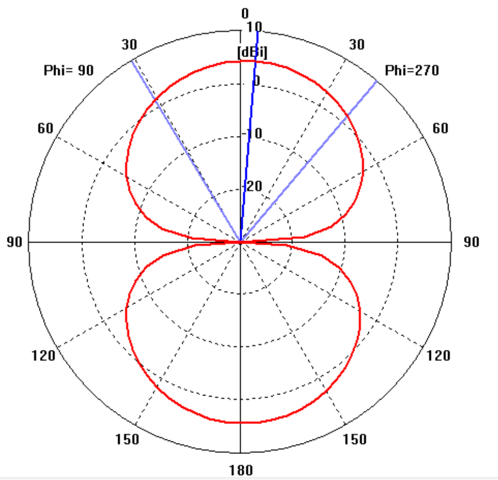
From the surface current plots shown in the fig.3.12.a,b,c, it is clear that the flow of the surface current concentrates in the C-shaped slot at 3.5 Hz , in the C-shaped slot and the pair of CSRs in the frequncey of 5.5 GHz and 8 GHz respectively and hence avoiding the use of 3 extra band stop filters.

3.4 RADIATION PATTERN:

3.4.1 E-PLANE:



a



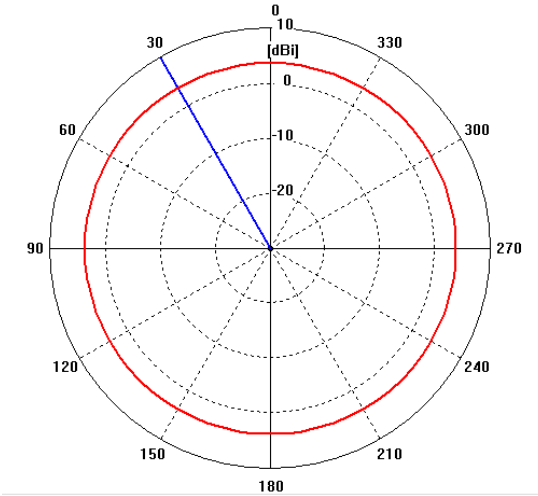
b.

Fig.3.13. a. Radiation pattern in E-Plane for the primitive antenna.

b. Radiation pattern in E-plane for the triple band notch antenna.

The E-plane radiation pattern looks like a dumbbell shaped structure because the alternating electric current enters the antenna through the feed line-patch junction and leaves the antenna through the radiating edge of the patch and hence they form an electric field pattern having field maxima at the radiating edges in the direction of radiation and field minima at the center of the patch hence a dumbbell shaped radiation pattern is formed (i.e. bi-directional in nature).

3.4.2 H-PLANE:

a. 

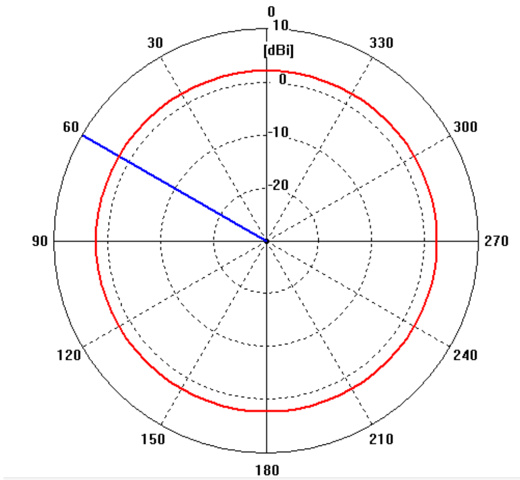
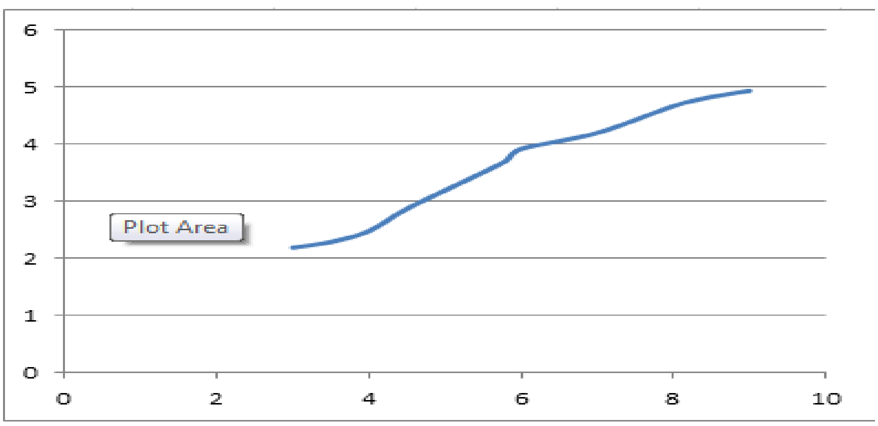
b. 

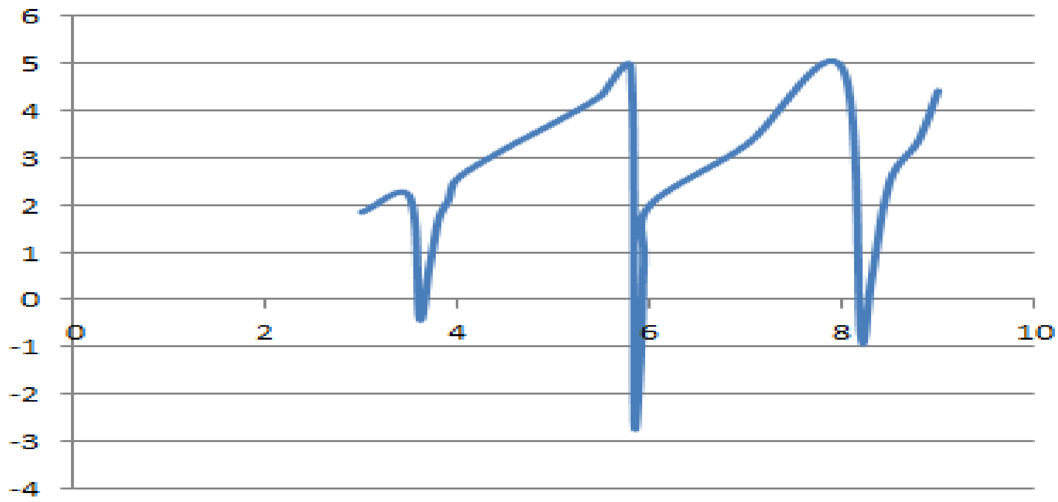
Fig.3.14. a. Radiation pattern in H-Plane for primitive antenna.

b. Radiation pattern in H-Plane for triple band notch antenna.

Whereas the magnetic field that is induced due to the electric field is perpendicular to the electric field lines and hence surrounds the entire electric field lines and hence generating a complete spherical shaped radiation pattern. Therefore the radiation pattern of the H-Plane is circular in shape (i.e. omnidirectional in nature).

3.5. GAIN vs. FREQUENCY GRAPH:

a. 



b.

Fig.3.15. a. Gain vs. frequency graph for primitive antenna.
b. Gain vs. frequency graph for triple band notch antenna.

As we can clearly see from the fig.3.15.a. that the gain of the primitive antenna keeps on increasing with respect to the increasing values of the frequency.

Whereas we can see that the gain in the fig.3.15.b. belongs to the triple band notch antenna, hence the 3 sudden negative drop in the gain can be seen clearly. And for rest of the frequency range the gain keeps on increasing. The negative gains (in dB) indicates the descructive interference of surface currents at those frequencies leading to band-notch creation.

CHAPTER 4

- **CONCLUSION**
- **FUTURE WORK**

4. **CONCLUSION:**

1. To minimize the potential interferences between the UWB system and the narrow band systems, a compact CPW-fed planar UWB antenna with triple band rejection features was designed. First on the basic antenna individual notches are designed and their band-notch properties are studied. Then all the three notches are embedded onto the primitive antenna. While integrating all the notch elements utmost care has been taken to minimize the cross-coupling among them; so that their operation doesn't get hampered by the presence of other notch elements.
2. Antenna operates in the specified 3.1-10.6 GHz range and the notches are at 3.5 GHz, 5.5 GHz, 8 GHz.
3. Stable radiation patterns and consistent gain in the UWB band were obtained. The simulation results and other measurement results of the designed antenna show a good agreement in terms of the VSWR, antenna gain, and radiation pattern.

5. **FUTURE WORK:**

1. Time Domain Characteristics of Micro strip Antenna (for primitive antenna, antenna with single band-notch characteristics, antenna with dual band-notch characteristics and antenna with triple band-notch characteristics).
2. Fabrication of prototype antenna will be carried out in future and measured results will be compared with simulated results.

6. REFERENCES:

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