Controllable Notched Edge Tapered Rectangular patch antenna using U-slot line feed and DGS for UWB Applications

Thesis

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By

SUNIL SHARMA
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(Sunil Sharma)
(Author)

Pantnagar
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C E R T I F I C A T E - I

This is to certify that the thesis entitled **"Controllable Notched Edge Tapered Rectangular patch antenna using U-slot line feed and DGS for UWB Applications"** submitted in partial fulfillment of the requirements for the degree of **Master of Technology** with major in **Electronics & Communication Engineering** and minor in **Information Technology** of the College of Post-Graduate Studies, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, is a record of bona-fide research carried out by **Mr. Sunil Sharma, Id. No. 52460** under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation and source of literature have been duly acknowledged.

29/08/19

(Paras)
Chairman
Advisory Committee

Pantnagar
August, 2019

C E R T I F I C A T E - II

We, the undersigned, Members of the Advisory Committee of **Mr. Sunil Sharma, Id. No. 52460**, a candidate for the **Master of Technology** with major in **Electronics & Communication Engineering** and minor in **Information Technology,** agree that the thesis entitled **"Controllable Notched Edge Tapered Rectangular patch antenna using U-slot line feed and DGS for UWB Applications"** may be submitted in partial fulfillment of the requirements for the degree.

(Paras)
Chairman
Advisory Committee

(Abhishek Tomar)
Member

(Ashok Kumar)
Member

C O N T E N T S

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LIST OF ABBREVIATIONS

CPW	Co-Planer Waveguide
CSRR	Complimentary Split Ring Resonator
dB	Decibel
DGS	Defected Ground Structure
EM	Electromagnetic
FEM	Finite Element Method
HFSS	High Frequency Structure Simulator
IEEE	Institute of Electrical and Electronics Engineers
MSA	Microstrip Antenna
PCB	Printed Circuit Board
RF	Radio Frequency
SMA	Sub Miniature Version A
SRR	Split Ring Resonator
TEM	Transverse Electro Magnetic
TLM	Transmission Line Model
UWB	Ultra Wide Band
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

LIST OF SYMBOLS

ε	Permittivity
μ	Permeability
ε_r	Relative Permittivity
μ_r	Relative Permeability
f_r	Resonance frequency
$\vec{E}$	Electric field intensity
$\vec{H}$	Electric field intensity
$\vec{k}$	Wave vector
c	Velocity of light in free space
ε_{reff}	Effective permittivity
μ_{eff}	Effective permeability
ε_0	Permittivity of free space
μ_0	Permeability of free space
$\vec{D}$	Electric field density
$\vec{B}$	Magnetic field density
∇	Del operator
e	Charge of electron
ŋ	Antenna efficiency
S_{11}	Return Loss
$tan\delta$	Loss Tangent
Γ	Reflection Coefficient

Introduction

For the modern-day systems used in wireless communication, one of the most critical parts used is antenna. So during the designing stage of an antenna, the essential key components that are needed to be given due consideration are that it must have a compact size, wide bandwidth, and a reasonable gain. Relaxation in system required is seen if a favorable design of the antenna is obtained and improves the overall performance of the system. In modern-day wireless communication antennas of different shapes and sizes can be seen conforming to the requirement and advancement in modern technology. The several kinds of antennas are wire antenna in form of straight wire, helix or loop, aperture antenna used in spacecraft, reflector antennas or parabolic antennas with large diameter used for information transmission or reception to and from long distances.

With increasing requirements of compact systems for mobile and wireless communications, the demand for smaller low-profile antennas has lead the Microstrip patch antenna to the limelight. Microstrip patch antenna (MSA) has proven its utility to fulfill all the requirements of modern systems for wireless communication mentioned above, as an isolated antenna can cover many specific application needs**.** The concept of the patch antennas is firstly proposed by **G. Deschamps *et al.*** in **1953**. However, Munson and Howell in the 1970s have developed the first practical antenna. In most basic form a microstrip patch has a radiating patch of metal on its one side of a dielectric substrate and on another side of substrate a ground plane of same metal as that of patch is present. The dielectric substrate has permittivity value ranging between 2.2 to 12 and plays a decisive role in its working. The various shapes of MSA are rectangular, triangular, square, circular, semi-circular, sectoral, and annular ring shapes. The most often used shapes of patch are rectangular and circular due to their simplicity of fabrication.

In terms of the resonant frequency of the patch, it is very flexible for a selected shape and mode of operation **(Pozar, 1992)**. The antenna operating frequency depending on the application is decided by the patch dimensions, which are calculated by using Transmission Line Model (TLM) of the patch using certain equations. The feed provides the electrical energy to the patch of antenna which is thereafter gets converted into electromagnetic energy while transmission and vice versa. There are different feeding methods in MSA like aperture coupled feed, coaxial feed, and microstrip line feed. So to have properly matched impedance an appropriate feeding method is to be selected.

The microstrip patch antenna has many advantages over the other antennas like the ease of fabrication applying modern-day fabrication methods, low profile, economical, compatible to both surfaces having planar and non-planar symmetry and when seated on stiff surfaces it is mechanically vigorous.

Although the patch antenna has numerous advantages over the other antennas, it also has certain drawbacks like lower efficiency, low power, narrow bandwidth, high Q, specious feed radiation. However, their limitations can be lessened by using certain methods, like by increasing the height of the substrate, change in efficiency and bandwidth is observed. But an increase in substrate height can result in undesirable surface waves, which extract the power from the input available for radiation. These surface waves traveling within the substrate get scattered at the bends and discontinuities of surface, e.g. truncation of dielectric and ground plane, leading to degradation of antenna radiation pattern and characteristics of polarization. The surface waves can be removed by using the cavities without having much effect on bandwidth. The array arrangements of radiating patch can be used for specific applications where the size and area are not a limitation. These can also overcome the problem of lower gain and low power **(Supriyo Dey *et al.*, 1996).**

As with the increasing trend in miniaturization of wireless systems, it has become necessary to make the compact size microstrip antenna and operate in wider bandwidth (UWB) so that, they can be part of these modern-day wireless communication systems. The first and foremost important requirement which is to be fulfilled while designing of UWB antenna is the coverage of extremely wide impedance bandwidth. For UWB applications the US FCC (Federal Communications Commission) in 2002 has issued an unlicensed band of frequency i.e. 3.1 GHz to 10.6 GHz. Consequently, bandwidth up to 7.5 GHz is covered by a practicable UWB antenna. And the return loss for the entire ultra-wideband should be less than -10dB. For wireless applications of indoor used devices, the omnidirectional property of the radiation pattern is required, so that convenient communication between both transmitting and receiving point is achieved using the UWB antenna. As a result, the uniform gain and low directivity are desired in all possible directions.

While designing the UWB antennas the radiation efficiency is also an important requirement. Due to low power transmission into space, a higher value of radiation efficiency is required. Last but not least the sufficiently small size UWB antennas is required so that they can be easily merged with various equipment as the UWB technology is largely employed for indoor and portable devices.

The UWB technology is dissimilar from traditional narrowband radio systems (usual bandwidth less than 10% of center frequency) for transmitting modulated signals in terms of their amplitude, frequency or phase of sinusoidal waveforms. The information transmitted by UWB systems is done by generating short pulses of radio energy at only specific instants of time which covers large bandwidth and validating the time modulation. Because of these properties, the UWB technology is broadly used in numerous applications like indoor positioning, radar/medical imaging, and the data selection of target sensor. One of the difficulties faced while implementing a UWB system is designing a suitable or optimal antenna **(Lim *et al.,* 2010)**.

There are various techniques that have been used for raising the parameters of conventional microstrip patch antennas, like using stacking, different feeding techniques, Frequency Selective Surfaces (FSS), Electromagnetic Band Gap (EBG), Defected or modified Ground Structure (DGS), metamaterial, and many more. Among all the techniques mentioned above the microwave devices with Defected Ground Structure (DGS) have achieved popularity as they have enhanced the parameters due to their easy structural design. The etched out slots or the defects made on the ground plane of microstrip circuit is called as Defected Ground Structure (DGS). Single or multiple defects made on the ground plane may be treated as DGS. **Lu *et al.* (2011)** has proposed the same methods of slots cutting on a ground plane to reduce the effect of ground plane on the antenna, which was earlier used to introduce the notch characteristic.

The current distribution gets disturbed due to defects made on the ground plane affecting the transmission line characteristics by using parameters like the slot resistance, slot capacitance, slot inductance to line parameters like the line resistance, line capacitance, and line inductance. In other words, the defect etched out of the ground plane under the microstrip line alters the effective line capacitance and line inductance by adding the slot resistance, capacitance, and inductance. At the beginning they were used as filters under the microstrip line. But now DGS has been used to accomplish the band-stop characteristics. Along with enhancing the bandwidth and gain of microstrip antenna, the DGS is also used to suppress the higher mode harmonics, mutual coupling between neighboring elements, and for improving the characteristics of radiation of the microstrip antenna cross-polarization is used (**Khandelwal *et al.*, 2017**).

Due to large operating bandwidth value from 3.1 to 10.6 GHz, the UWB systems are liable to suffer from the interfere with the existing narrowband communication systems like IEEE802.16 (3.3–3.8 GHz) WiMAX system and IEEE802.11a (5.15–5.825 GHz) WLAN system and. External bandstop filters can be used with the antennas having UWB applications to lessen the interference issue, but it will make the system bulky and it also adds non-linearity to the system. So, UWB antennas with integrated capability of band-rejection are generally preferred. The techniques are categorized broadly into two categories, (a) by using resonant slots, (b) by using parasitic resonators on the reference UWB antenna. In the first case, the slots are either cutaway from the radiating element or inserted in the ground plane, or can be inserted in the feed-line itself. The latter consists of parasitic resonators placed nearby to the feed line or in the vicinity of the radiating element. The tuning of the rejection band can be done by changing the dimensional parameters and position of these slots or the parasitic resonators. All the methods mentioned above have their own pros and cons. When slots are used on the radiating element of the UWB antenna to create a notch, basically it creates destructive interference of the currents at a particular frequency. On the other hand, placing slots on the ground plane or on the feed line itself behaves as a pre-filter that creates a rejection in the UWB impedance bandwidth. Using the parasitic resonators also effectively creates a notch at the desired band. These techniques basically filter out the specific band from the UWB transmission, but it also adds some undesirable effects in time domain as well as in frequency domain behavior of the UWB system. These slots and parasitic elements behave as resonant type band-reject filters and filters a specific spectral component and hold the energy so that the UWB antenna ceases to transmit or receive at that frequency. However, these are low Q-filters and can't hold the energy for a longer time. Eventually, the stored energy decays in form of spurious radiation or losses. This affects the transient behavior of the antenna and causes prolonged ringing effect on the transmitted pulse in time domain (**Malik, 2018**).

In the view of the above introduction, it, therefore, becomes necessary to propose a microstrip antenna which has a small size and wider bandwidth with controllable band rejection capability in the frequency range from 3.1 to 10.6 GHz for wireless applications. **Moghadasi *et al.* (2009)** has presented a planar monopole antenna having microstrip line fed for UWB applications exhibiting desired band notching characteristics without changing the physical structure of antenna making unresponsive at certain frequencies.

Emadian *et al*. (2015) have given an impedance bandwidth enhancement method using a compact rectangular slot antenna showing dual band-notched characteristics using slots. **Liu *et al.* (2010)** presented a simple monopole microstrip antenna that uses a vertical strip coupled to patch providing the flexibility in controlling the rejected frequency band of UWB system operation.

Based on the requirement of today communication services for 5G and other applications following objectives has been set for proposed work,

Objective of the Thesis

The objectives for the proposed research work are as follows

1. Study of the earlier designed ultra wideband MSAs for wireless applications.
2. Study of different slot structures and their effects on the UWB antenna.
3. Study of the effect of DGS to improve antenna performance.
4. Design and simulate a compact microstrip patch antenna that exhibits ultra-wideband operation range.
5. Analyse the effect of slots and DGS on the compact MSA
6. Fabrication of the optimized design using a PCB prototype machine.
7. Test the fabricated MSA for required radiation properties.
8. Comparison with previous work of the measured results.

To achieve the above-mentioned objectives following steps are used

1. The study of earlier work is done in the field of MSA for wireless applications in detail.
2. Then the Study of different slots and DGS techniques is done and their effects on antenna performance.

3. Designing a conventional MSA suitable for wireless communication with the help of the transmission line model (TLM) is done.
4. Size reduction or performance improvement of MSA is done by optimization.
5. The optimized proposed antenna is simulated using a high-frequency structure simulator (HFSS) and to achieve the desired simulation objective with a parametric study.
6. The proposed antenna is fabricated using a PCB prototype machine.
7. The characteristics such as reflection coefficient and VSWR etc. of the antenna are measured using VNA.
8. The simulated and measured results are compared to verify the performance in the given band of frequencies and applications.

Outline of the Thesis

Chapter 1: The chapter gives a brief introduction about microstrip patch antenna and its advantages and applications, basic idea about DGS and notching, and steps to be followed to attain the desired objective which is set for the research work proposed.

Chapter 2: The chapter gives a review of the literature of earlier research work which has been performed in the field of MSA, DGS, and notching.

Chapter 3: The chapter describes the materials and methods used for carrying out the proposed research work. It contains the sequential steps which are being executed in the designing of the antenna proposed.

Chapter 4: This chapter deal includes the simulated results obtained from HFSS, the process of fabrication of proposed antenna using a PCB prototype machine, along with the measured results of proposed antenna obtained using VNA. The various antenna parameters like reflection coefficient, peak gain, radiation patterns, and VSWR are compared in this chapter.

Chapter 5: The chapter gives the conclusion of the whole thesis work, its applications and the possible future scope of proposed research outcome.

Review of Literature

To accomplish the objectives mentioned in the previous chapter for designing, simulation, fabrication and testing of the monopole antenna having notched characteristics for Ultra Wide Band application; the study of previously done work is needed to be considered in the field of UWB antenna. The significance of DGS and notching phenomenon and their effect to enhance the antenna performance characteristic for different frequency and size has been reviewed. Some of the selected literature is presented here.

Chung *et al.* (2005) have proposed a microstrip monopole antenna with a narrow slit on the patch. The used substrate is FR4 of thickness equals 1.6 mm & ε_r= 4. Antenna proposed in the work has rectangular patch having dimension 16 mm×14 mm, slit of 7 mm height 1 mm in width, which on shifted 3.2 mm away from centre of patch. The feed line width is 2.6 mm and has resonating frequency of 4 GHz. The narrow slit provides longer surface-current paths which result in controlling impedance bandwidth of antenna by changing its slit height. Selecting the appropriate height value height of narrow slit, the wide-band characteristic was obtained for the proposed antenna. It has return loss value less than -10dB for band of 3.1 GHz to beyond 11 GHz. The gain with flatness of 1.7dB is seen over the complete frequency band.

Kim *et al.* (2005) have proposed UWB antenna with rejection of WLAN band by making two parasitic patches on the bottom layer of antenna. The dimension of proposed antenna are 30×30×1 mm^3 and is fabricated on FR4 substrate with ε_r = 4.6. The proposed structure has the staircase and ball shape to increase effective electrical length at lower frequency of 3 to 4 GHz. Also parasitic elements with dimensions of 1×16 mm^2 are tilted by 21 degrees. These elements help in WLAN band rejection. The ground is tapered in circular shape at the corners showing broader bandwidth raging 3 to 18 GHz. The change in length of parasitic element can help in tuning of notched frequency from 6, 5.5 and 5 GHz with length 14, 16 and 18 mm respectively. The chosen length 16 mm has rejected the frequency band 5.15 to 5.825 GHz.

Kim *et al.* (2006) have designed a novel UWB antenna with band-rejection capability using a parasitic strip. The antenna has a half ellipse-shaped patch with dimensions 20 mm×20 mm×1 mm fabricated on FR4 substrate with $\varepsilon_r = 4.6$. The operating range is from 3 to 17 GHz frequency band and the parasitic strip has rejected the frequency band 5.15 GHz to 5.825 GHz. An ellipse-shaped slot is made on the patch the optimized values of major and minor axis helps to get wider bandwidth. The stair case tapering is done on radiating patch and ground is tapered in circular shape. Effecting the coupling between monopole patch and ground plane for proper matching of impedance, enhancing the impedance bandwidth for proposed antenna. The parasitic strip is added which has eliminated the band 5.15 to 5.825 GHz. The tuning of notched band can be easily done by changing the width of strip. The measured antenna results have operating range from 2.9 to 17.4 GHz and rejecting 5.25 to 5.85 GHz band with average gain of 3.5 dBi.

Hong *et al.* (2007) has presented an arc-shaped radiating patch with dimensions of 24×35×0.8 mm^3 as a UWB antenna and microstrip feed line is used to feed antenna. A wider bandwidth of 3 GHz to 10 GHz is acquired by making couple of bevels on ground plane's upper edge. On ground plane's bottom side of additional two semi-circular slot are cut ,further improving the performance of antenna at high frequency, also improved the matched impedance and characteristics of radiation has been observed. Two stubs of T-shape are added inside elliptical slot which provides 5 to 6 GHz band notch of Wi-Fi. Measured S_{11} of antenna proposed has attained large bandwidth ranges 2.95 to over 11GHz with notched band of 5 to 6 GHz.

Chu *et al.* (2008) has presented a compact UWB antenna with CPW-feeding with dimension 30×26×1.6mm^3 having notching of dual band, obtained by etching two concentric slots of C-shape in patch. The tuning of desired notched frequency can be done by varying the length of C-shaped slot according to half wavelength formula. . The microstrip antenna proposed operates on the UWB region of 3.1 to 10.6GHz and goes further to mentioned band 10.6 GHz by FCC with VSWR<2, and has rejected the WiMAX band 3.3 to 3.8 GHz and 5 to 6 GHz defined for IEEE802.11a and HIPERLAN/2 WLAN. The gain of proposed antenna varies between 2 to 5 dBi in the UWB region. The notching is done in steps, first a simple UWB antenna is made, and then a C-shaped slot is made on the patch rejecting 5 to 6 GHz of frequency. The interference between UWB system and narrowband systems can be reduced by second slot made on patch.

Yin *et al.* (2008) designed a circular monopole antenna along with notching of multiple narrow bands. Firstly designing of monopole antenna of circular disk shape is done, operating over 3.1 GHz - 10.6 GHz with VSWR less than 2. The substrate with $\varepsilon_r = 2.65$, thickness of 0.5 mm is used. To remove the interference with the other wireless systems, frequencies 2.4 GHz (WLAN), 3.5 GHz (WiMax), and 5.5 GHz (WLAN) are selected as centre frequencies of stop band , such that antenna stop working on these frequencies. To obtain the first notch at 2.4 GHz, proposed antenna has used an L-type band-stop filter. Then the use of a SRR brought the second notch at 3.5 GHz. Finally to get the third notch at 5.5 GHz, L-shape branches on radiating patch is made. The antenna has an operating over 2.2 GHz to 10.8 GHz along with four precise notched bands.

Jiang *et al.* (2009) have designed a novel UWB monopole antenna which is compact in size and also has band notching characteristics. The antenna designed has simple rectangular patch with size of 15×5 mm^2 with band-stop characteristics controlled using slots of inverted-L-shaped which were made on ground with size of only 35×35 mm^2.The substrate used is FR4 with thickness 1.6mm and $\varepsilon_r = 4.4$. And the structure has notched band from 4.8 GHz to 5.7 GHz. The proposed antenna has value of VSWR$\leq$ 2.0 over frequency band 2.8 to 10.7 GHz, while the capability of band rejection is shown for band 4.8 to 5.7 GHz. To improve upon impedance bandwidth of proposed antenna, a square notch on top of ground plane is made. Also the notching of frequency response is done by etching two inverted-L-shaped slots on ground plane around feed.

Choi *et al.* (2009) has presented UWB antenna of small size along with the characteristic of notching by employing a spoon shaped slots made on radiating patch of antenna. The antennas operate over the UWB region 3.1 GHz to 10.6 GHz and have notched frequency band from 4.8 to 6.3 GHz where the VSWR is more than 3. The antenna has dimension of 8×15×1 mm^3.The presented antenna has two parts: part one has a radiating patch with LTCC with $\varepsilon_r = 7.5$, second, the PCB with $\varepsilon_r = 4.5$ feeds the patch. In patch's backside, pad is attached with PCB working as impedance transformer. Connection between pad and radiator is made using small hole. The base of patch is tapered in half circle shape leading to smooth transition for increasing the bandwidth. The spoon-shaped slots are cut on tapered section providing band notched characteristics and resonant frequency of them is decided by slot size. The peak gain of 2.26 dBi and average gain of 8.7 dBi is obtained at 5.5 GHz.

Liu *et al.* (2010) has proposed a compact monopole antenna wit band-notched characteristic which is capable for use in ultra-wideband (UWB) applications. The radiating patch of proposed work has a square shape with dimensions of 15×15×1.6 mm^3 , printed on substrate having FR4 substrate ε_r = 4.4 and tanδ=0.02 .The dimensions of ground plane has length of 13 mm and width of 30 mm. The square patch has a vertical coupling strip which when properly designed provides frequency rejection over band of 3.05 GHz to 11.15 GHz. The proposed antenna has measured impedance bandwidth from 3.05 GHz to 11.15 GHz with return loss less than -10 dB, while rejecting the band of 5.12–6.08 GHz. Also the tuning of stop band can be easily done between 4.94 GHz to 6.72 GHz by changing the strip width between values 1 to 5 mm, whereas for different gaps values the shift is from 4.86 GHz to 6.28 GHz for variation in value from 0.1 to 0.3 mm. The proposed antenna has gain variation from 3.02 to 3.92 dBi in pass band, and more than 82% of the radiation efficiency is obtained.

Mohammadian *et al.* (2010) has designed a basic planar slot antenna UWB applications, the measured results shows impedance bandwidth from 3 to 11 GHz. The antenna is printed on FR4 substrate with ε_r=.4.4, thickness equals 0.8 mm and has notched triple bands. The coplanar waveguide (CPW) feeding is used to feed the proposed antenna .The multiple band-notching characteristic is achieved by using three slots of inverted U-shape on the patch. The standard design equations were employed for designing of feeds of antenna. The antenna has a rectangular shape aperture which has tapered-shape stub for getting proper excitation. The parametric study is done on dimension of the proposed slot antenna to procure operation in UWB band. The characteristics of band rejection are realized by using inverted slot of U-shaped etched out on patch. The first slot has generated notched band of WLAN1 of 2.4 GHz. Changing the value of length of slot from 25.3 to 39.7 mm, helps in the tuning of notched band from 3.5 to 2.5 GHz whereas notched bandwidth remains same. The second slot has generated notched band of in WiMAX of 3.5 GHz. Changing the value of slot length slot from 27 to 29 mm, the tuning of notched band is done over 3.68 to 3.26 GHz whereas notched bandwidth remains same. The third slot has generated notched band of in WLAN2 of 5.5 GHz. Changing the value of length of slot over 15.2 to 23.2 mm, the tuning of notched band is done over band 5.5 to 4.39 GHz whereas notched bandwidth remains same. The average gain of about 4.5 dBi is shown by antenna proposed, whereas at the three notched bands the values have shown reduction of 3, 4.5 and 6 dBi.

Zhang *et al.* (2010) has presented the monopole patch of an elliptical-shape with two slots for UWB applications. The basic structure of proposed antenna is made on Rogers' RT/ Duroid 5880 substrate having thickness of 31 mil and $\varepsilon_r = 2.2$ with a loss tangent of 0.0009. To feed the antenna line feed of 50 Ω characteristic impedance is used. The ground plane on opposite side of patch is etched partially removed to make it a monopole antenna. The size of elliptical patch decides the operating frequency of the monopole antenna. However the design proposed has used two slots which also have a significant effect on the operating frequency of antenna. A frequency notch of desirable range is attained by varying the position and size of slot on patch. The measurement of return loss is done over 3.4 to 10 GHz band. The frequency notch is obtained at around 5.2 GHz. The diode is used as switch at the centre of two slots. For the ''ON'' position of switch, single slot changes to two slots causing the antenna to work over UWB region with no notching property, whereas for the ''OFF'' position of switch antenna shows band-notch characteristic over UWB region.

Zhang *et al.* (2010) has presented a band-notched UWB monopole antenna with novel radiating patch having two segments. The antenna has make use of segmented circular patch antenna printed on dielectric substrate of Wangling F4Bm-2 of ε_r=3 and thickness equals to 1.5 mm, loss tangent equals 0.0015. A circular patch printed on substrate is fed by tapered microstrip feed line which has worked as an impedance transformer smoothly transforms the impedance of patch to 50 Ω.A symmetrical slots pair are made on patch to get two parasitic elements which has helped in obtaining band notching. The parametric variation of dimensions like distance between slot and centre of circular patch, width of slots, and circular patch's radius has affected the tuning of notched band. For explaining the band notching operation concept of an equivalent parallel RLC circuit is used. The variation of slot movement and its width changes the value of capacitance and inductance leading to change in quality factor and the notched frequency.

Nguyen *et al.* (2011) have proposed an antenna with dimensions of 25×29×0.8 mm^3 printed on FR4 substrate $\varepsilon_r = 4.4$ and tanδ=0.02. The patch has an arc-shaped edge with a simple rectangular ground plane having four different slots. The optimization is applied on location and shapes of the slots. A rectangular slot was made on the left side of the edge of patch, the slot has dimensions of about quarter of guide wavelength , it has helped in notching of WiMAX band centred about 3.55 GHz. Whereas the higher frequencies are notched by making three different semi-circular slots made on patch. The first slot has radius equals 5mm giving slot length equals to half of guided wavelength helping in removing the WLAN band centred about 5.45 GHz in and the two coupled slots has radius equals 3.8 mm and are cut above and below the above slot on patch and the length is calculated to be half of guided wavelength giving 7.4 GHz as frequency helps in notching the downlink frequency of X-band in satellite communication.

Lee *et al.* (2011) has presented an Ultra Wideband microstrip antenna with diamond slotted patch providing enhanced bandwidth. The antenna simulated result has return loss less than –10 dB from 3.28 GHz to 19.64 GHz while for the measured result the first resonant frequency was noted at 3.28 GHz with S_{11}= -20.66 dB, followed by 5.89 GHz with S_{11}= –23.81 dB, 8.67 GHz with S_{11} = –48.95 dB, 12.52 GHz with S_{11}= –25.41dB, 15.23 GHz with S_{11}= –22.02 dB and 17.54 GHz with S_{11}= –24.08 dB. And the introduction of diamond slot at the radiating patch portion has given a resonant frequency at 12.25 GHz in the simulated result and 12.52 GHz in measured result.

Mishra *et al.* (2012) have proposed a circular monopole antenna which is fabricated on an FR4 epoxy substrate with ε_r = 4.4 and tanδ=0.02 to covers the UWB frequency and provided with characteristics of dual notched band. The notched characteristics were achieved by etching C-shaped slots on radiating patch and two L-shaped symmetrical slots in ground. The C-shaped slot of patch has helped in the rejection of frequency band 3.3 to 4.2 GHz which is used by WiMAX systems and C-band satellite communication. The tuning of the centre frequency of WiMAX band can controlled by altering the width, length, thickness and gap between legs of C-slot. The L-shaped symmetrical slot in the ground plane with defected structure has helped in rejecting of the frequency band of 5.1 to 5.9 GHz which is used in WLAN systems, also the tuning of central frequency of the notched band can be done by changing the width and length of the slot. The radiation efficiency of 80% is shown by proposed antenna except over notched bands whereas antenna peak gain varies between 2 to 5 dB over the complete operating band 2.5 to 10.6 GHz range except the notched band.

Moosazadeh *et al.* (2012) have designed a slotted square patch with compact dimensions of 12 × 16 × 1.6mm^3 on FR4 substrate fed using microstrip line showing UWB performance with characteristics of dual band-notched. The ground is reduced in size to make it a monopole antenna. The slots dimensions are selected using the empirical formula so as to obtain two notched bands at desired centre frequencies. The pair of mirrored slots of inverted L-shape has helped to reject the existing WiMAX, whereas the second band notched is WLAN band which is achieved by an inverted T-shaped strip added in the radiator. For the bandwidth enhancement of the antenna a π-shaped conductor is added on ground plane. The measured results show that proposed antenna has wide bandwidth from 2.5 to 10.8 GHz with two notched frequency bands of 3.2 GHz to 4.2GHz and 5GHz to 5.9 GHz.

Mok *et al.* (2013) has designed a microstrip patch antenna with dual- or triple-band obtained by etching U-slots on radiating patch of proposed antenna, it has applied it to the probe fed L-shaped radiating patch, M-shaped probe fed patch, coax-fed stacked staircase, and last on aperture coupled stacked patches. All of the above cases have involved complicated feed, using more than one patch, and more than one layer is present. In proposed paper the method is applied on a broadband microstrip patch antenna with U-slot. With an additional U-slot etched on patch two bands are obtained, whereas with two additional U slots on patch give triple-band antenna.

Aghdam *et al.* (2013) has proposed a new microstrip monopole antenna with variable band-notch characteristic using a balloon-shape patch with ground having two circular configurations. The band 5.1 GHz to 8.2 GHz is being notched from the operating frequency band 2.7 GHz to 22 GHz. Also the Omni directional radiation pattern is obtained for the entire UWB bands. The notch band at 5.5 GHz is achieved by inserting the inverted U-shape slot on radiating patch and this frequency can be tuned by varying the length of the inverted U-shape slot. By applying optometric on size of U-slot length from 5.2 mm - 7.6 mm the notch-frequency has shown a shift from 5.1 GHz to 8.2 GHz. Also change in of circular slot's radius of ground plane shows changes in the amplitude of the return loss over frequency band of 17 GHz to 20 GHz.

Sayidmarie *et al.* (2013) has proposed a monopole antenna with dual band crescent shape planar structure which is useful for WLAN application. The shape of crescent antenna is obtained from an arc patch antenna. The antenna covers first band at 2.5 GHz having bandwidth of 342 MHz (2.363- 2.705 GHz) with reflection coefficient -16dB, which covers the first band of WLAN applications (2.4-2.48 GHz). The second band at 5.77 GHz has a bandwidth of 4.075 GHz (4.46-8.535 GHz), having reflection coefficient -37.2dB, covering the second and third bands of WLAN applications (5.15-5.35), (5.725-5.825) GHz. The proposed antenna has peak gain in the range of 2.123 to 2.5 dBi for the lower frequency band and 3.35-4.6 dBi for the higher frequency band. And the maximum value of 4.2 dBi gain of the antenna is obtained at the frequency of 5.95 GHz. The radiation efficiency of 89.2% at a frequency of 5.388 GHz is noticed in simulations. The length and width of the arc antenna decides the resonant frequencies and the bandwidths of the proposed antenna.

Gao *et al.* (2013) has presented a compact dual band-notched antenna for UWB antenna applications with dimensions of 20×27×1.6 mm^3 fabricated on FR-4 substrate with thickness equals to 1 mm and $\varepsilon_r = 4.4$.The capability of WLAN band rejection is obtained by removing out C - slot from patch, whereas WiMAX band is notched function by using an extruded a stub of L-shaped from ground. By changing length in both the structures the tuning of two notched band can be easily done. The proposed antenna has operating frequency band from 2.89 to 11.52 GHz, and return loss in notched band with centre frequency 3.6 GHz and 5.65 GHz are -2.1 dB and -1.9 dB.

Fayadh *et al.* (2013) has proposed a band notched patch antenna with very small dimensions and the results are accepted for the UWB that was allowed by FCC. Taconic TLY -5 substrate material with dimension of 26 mm×30 mm×1.5748 mm having $\varepsilon_r = 2.2$. For obtaining the UWB applications, impedance bandwidth has been maximized by slotting the upper edges of patch with three slots of 8mm depth and 2 mm width, the lower edges are tapered with staircase having four steps and five steps respectively. The simulation results cover the frequency range of 3.4 GHz to 12 GHz at four steps and from 3.8 GHz to 12 GHz at five steps with S_{11} less than -10dB. The simulated results has resonance frequencies for four step stairs at 4 GHz, 5.9 GHz, and 8 GHz while for five step stairs at 6 GHz and 9 GHz. The measured resonance frequencies for four steps stairs are 6.5 GHz and 8 GHz while that for five steps stairs are 7 GHz and 9.5 GHz The radiation patterns are nearly Omni-directional radiations over the UWB bandwidth.

Wang *et al.* (2014) has given a design of new compact 32×28×1.4 mm^3 ultra-wideband antennas which have three notched bands. The structure of the proposed antenna has a circular patch and has symmetry at every point. The ground has been modified to introduced a wide operation frequency band from 2.9 to 13.4 GHz with $S_{11} < -10$dB. The two arc-shaped slots in the radiating patch has helped to get two sharp notch bands, one for the frequency range 3.3 to 3.7 GHz and the other from 5.15 to 5.35GHz. Whereas the frequency band of 7.25 to 7.75 GHz is being notched by etching a slot of U-shape in the ground plane. The movement of these notched bands are easily controlled by varying the radius and length of the slots, without having any effect on the characteristics of the proposed UWB antenna at the other frequencies.

Awad *et al.* (2015) has presented designs of both planar ultra-wide band antennas with two rejected bands. The proposed antenna consists of a rectangular patch which is etched on FR-4 substrate with 50Ω feed line. The round cuts are made on rectangular patch at each corner and one slot is made in the ground plane to improve the band width and matching. The bandwidth obtained after simulation has return loss $S_{11} <= 10$ dB for 3.42 to 11.7 GHz. By inserting two slots in patch and feed the rejected bands of the WLAN and X-bands are achieved. The simulated results of the proposed antenna indicate higher gain at the pass bands 6 dBi at 11.7 GHz whiles a sharp drop at the rejected bands is seen. The radiation pattern in the E-plane is of dipole shape and in the H-plane it's almost omnidirectional.

Ahsan *et al.* (2015) has presented a printed planar antenna with a simple and intelligent structure which is designed for Ku/K band in satellite communication systems. The patch of the proposed antenna is made by cutting few rectangular slots and the radiating element is extended to some extent. The optimization of final design of antenna is done and is fabricated on ceramic–poly-tetra-fluoro-ethylene as substrate materials having dielectric constant $\varepsilon_r = 10.2$. The antenna is easy to fabricate as it is simple and has dimension of 40 × 35 × 1.905mm^3. The experimental results show that the proposed antenna works on a wide frequency range of 12.0 to 16.4 GHz at lower band, whereas upper band covers the range of 17.53 to 19.5 GHz. The antenna has provided gain in range of 3.14 to 4.68 dBi for lower band and for upper bandit is 2.03 to 3.65 dBi.

Emadian *et al.* (2015) has designed a small rectangular antenna with slot giving dual band notched characteristics and has improved impedance bandwidth. The proposed antenna is printed on low cost FR4 substrate $\varepsilon_r = 4.4$ and loss tangent 0.0018 and fed by a CPW transmission line. Moreover, the proposed antenna provides a very wide impedance bandwidth from 2.6 to more than 23 GHz. The proposed antenna features a small physical size of 15×15×1.6 mm^3. By removing two triangular notches of proper size from the corners of rectangular patch good impedance characteristics are seen, and to further improve bandwidth of proposed antenna two semi-circle slots are made on both sides of the feed on ground plane.an elliptical ring slot on rectangular patch gives single band notched. Whereas to obtain dual band notched characteristics, two S-shaped parasitic elements are added on radiating patch. The dual notched bands are 3.1 to 3.9 GHz and from 5.1 to 6 GHz.

Khan *et al.* (2016) designed a monopole antenna with dual notched band characteristics with compact dimensions as 32×29.3×1.6 mm^3.Antenna Proposed is designed for UWB applications with band 2.9 GHz–16 GHz having the VSWR less than 2 and reject the band 3.1 GHz– 4.1 GHz (WiMAX) and 4.9 GHz –5. 9GHz (WLAN) respectively. There are two slots which are made in the radiating patch, large wider slot made on radiating patch rejects 3.1 GHz– 4.1 GHz and small narrow slot helps to reject the 4.9 GHz–5.9 GHz. Designed antenna has used FR4 substrate with $\tan\delta=0.02$, $\varepsilon_r= 4.6$.

Gupta *et al.* (2016) has presented multi-band antennas for wireless communication, having Stair case of hexagonal shape. The key point is it has eight different resonant frequencies 3.13 GHz, 8.89 GHz, 10.69 GHz, 16.79 GHz, 20.37 GHz, 26.06 GHz, 30.13 GHz, 36.26 GHz having gain 5.17dBi, 9.12dBi, 15.83dBi, 6.0 dBi, 5dBi, 5.84 dBi, 5.34 dBi, and 3.79 dBi, respectively. All of these resonant frequencies have S_{11} less than -10 dB and up to 15.83 dB of gain. The antenna has Rogers substrate with dimension 30 X 30 mm^2 and height of 1.6 mm. The Roger substrate has $\tan\delta=0.0013$, $\varepsilon_r = 3.0$. The antenna structure has staircase pattern introduced on both upper and lower edged of patch, the patch also has a hexagonal shape removed from it.

Mewara *et al.* (2016) has explained the designing and analysis of an ultra-wide band antenna which consist of an extra radiating patch which has shown bandwidth enhancement and band notch characteristic. The proposed antenna has a rectangular patch antenna which is fed by a 50 ohm microstrip feed line with dimensions 35 mm×2.88 mm. The rectangular patch dimensions are 16 mm×16 mm which is printed on the top side of 60 mm×55 mm×1.6 mm substrate which is FR-4 Material substrate with dielectric constant ε_r = 4.4 and loss tangent is 0.02. The π-shaped slot is cut on the extra radiating patch, which helps in improving the bandwidth and performance of antenna whereas the C-shaped slot which is etched on the front side radiating patch is use to obtain the notch band with frequency range 5 GHz to 5.8 GHz, which exempted the interference with WLAN band communication. The proposed UWB antenna on Simulation shows bandwidth of 12.65 GHz ranging from 2.0 GHz to 14.65 GHz, which fulfil the system requirements for WLAN and the UWB applications.

Ali *et al.* (2016) presented a compact Flower shaped microstrip Patch Antenna showing triple band-notched characteristics, the patch is of hexagonal shape. The simulated result shows that antenna operates over 2.72 GHz to 11.73 GHz with gain of 4 dB The three notched-bands are IEEE 802.16 i.e. WiMax 3.3 to 3.7 GHz and 5.25 to 5.85 GHz, IEEE 802.11a i.e. WLAN2 5.15 to 5.35 GHz and 5.725 to 5.825 GHz, Satellite C Band 3.7 to 4.2 GHz and ITU Band 8.025 to 8.4 GHz. All notches can be controlled. The Rogers RT/Duroid-6002 substrate has dimensions of 30 x 41 mm^2 with thickness of 0.381 mm. Partial ground 30 mm x 17.7 mm and on back side of feed a triangular cut is made on side of hexagon parallel to the feed the gap between feed and the strips two strips are added which being used to control the notches.

Gupta *et al.* (2017) a proposed a unique design for microstrip antenna with multi-band operation for the wireless communications. A distinctive antenna shape fed through 50Ω coaxial probe line feed. The four band having S_{11} less than -10 dB are obtained which are 2.06 GHz, 10.92 GHz, 16.30 GHz and 24.24 GHz , simulated gain at these frequencies are 6.2572 dB, 5.2190 dB, 6.9254 dB, 5.1175 dB and 6.3533 dB respectively. Various shape cuts are made in patch and ground to improve the performance like feed line has U-shape cut , bottom side of patch has staircase cut and ground has small rectangular cut. The antenna proposed has a size of 30 × 32 ×1.6 mm^3 , used Rogers's substrate with ε_r = 3.0 with a tanδ= 0.0013.

Suo *et al.* (2017) designed a dual-band notched ultra wideband microstrip antenna having semi-circular patch on substrate size of 32×30 mm^2, thickness of 1.6 mm. The dual-bands are notched by using a complementary structure of split ring resonator on patch. The rectangular CSR has two square split rings having same centre having small cuts etched out from metal plate, and the two splits on opposite sides of each ring are placed. The notched band are 3.3 GHz to 3.7 GHz (WIMAX) and 5.15 GHz to 5.85 GHz (WLAN) obtained by making complementary split ring on patch. The operating frequency band of 2.8 GHz – 12 GHz is obtained with gain of 2.3 dB to 6.3 dB, while less than 0 dB gain shown in notched band. The antenna also shows good omnidirectional radiation patterns in H-plane in the working band.

Saha *et al.* (2018) presented a slotted circular microstrip patch antenna with slot to operate in ultra-wideband region. The proposed antenna operates over frequency range from 4.0 to 40 GHz with 164% of fractional bandwidth with a $S_{11} < 10$ dB and VSWR < 2. The dimension of the proposed monopole antenna is o 28.1 mm × 17.1 mm×1.4 mm. The antenna proposed used FR-4 as substrate having $\varepsilon_r = 4.4$ and $\tan\delta=0.02$. The omnidirectional radiation pattern is exhibited by proposed antenna over entire bandwidth with peak gain more than 2.8 dB over entire frequency range and average radiation efficiency is 75%. The proposed antenna can found application in UWB communications systems including the C-band, X-band, Ku-band, K-band, Ka-band, WLAN, and future wireless applications.

Ali *et al.* (2018) has propose simple compact UWB antenna having decagonal radiating patch with truncated ground operating over wide impedance bandwidth of 3.0 to 12.66 GHz.. The proposed antenna has $S_{11} < -10$ dB (2.3-12.8 GHz) in measurement. The proposed antenna has [assed through various design evolution process or iterations. The "iteration 0" has antenna with decagonal patch with full ground plane and produces narrow multiband region. The "iteration 1" has lessened the ground resulting in wider impedance bandwidth. The "iteration 2" has truncated the ground plane resulting in wider impedance bandwidth covering from 3.0 to 12.66 GHz as allocated by FCC and showing resonances at frequencies 4.4, 8.25, and 11.4 GHz, respectively. The proposed antenna has shown gain from 1.1 to 5.06 dBi over the entire bandwidth, with a minimum value of 1.1 dBi at 5 GHz and maximum value of 5.06 dBi at 10 GHz. throughout the impedance bandwidth the antenna has an average efficiency more than 88%.

Hussain *et al.* (2019) has design a small size UWB antenna rejecting the WLAN band. Antenna proposed has a truncated patch rectangular in shape, U-slot is made on patch and ground plane is modified. Substrate used is Taconic TLY-5 with $\varepsilon_r = 2.2$. The truncation of lower corners of patch in circular shape has helped in achieving the wideband characteristics, while the use of U-slot on the patch has helped in achieving the notch. The antenna proposed works over 2.9GHz-23.5 GHz with a VSWR < 2 and band 4.9 GHz to 6.1 which is IEEE 802.11a and HIPERLAN/2 is notched. The moderate gain of about 6.1dB is shown by antenna, with omnidirectional radiation patterns. The key point is its compact with size of $13 \times 22 \times 0.8$ mm^3.

Siddique *et al.* (2019) presented an ultra-wideband antenna with compact size rejecting the WiMAX and WLAN bands. The antenna proposed has rectangular patch and partial ground which has been slotted and microstrip feed line is used for feeding of antenna. The dimensions are $30 \times 22 \times 1.6$ mm^3 and for notching the WiMAX and WLAN band respectively, parasitic resonator is positioned underneath radiating patch. The proposed antenna operates from 2.98 GHz to 12 GHz and VSWR ≤ 2 with 3.95 dBi of average gain of. Besides, antenna has notched 3.5 GHz and 5.45 GHz to remove the possible interference in pre-existing narrow-band services.

Bodo *et al.* (2019) has designed a rectangular micro strip-fed patch antennas, for frequency band of 2.0 - 2.8 GHz for Wi-Fi applications. A rectangular patch is splitted into two triangle-shaped patch antenna by diagonally making a cut on it which is then microstrip-fed. The proposed antennas is fabricated on Teflon as substrate with thickness 0.635mm and $\varepsilon_r = 2.2$ and $\tan\delta = 10^{-3}$ .Then the ground of conventional patch along with two triangle-shaped patches is changed in many steps to design the line fed monopole antenna to operate the in frequency band of 2.0 to 7.0 GHz. The concepts of current and voltage waves along with classical electrostatics approach solutions are used. Simulations have shown same antenna performances as that of a triple-band, a return loss bandwidth equals 29% with gain of 7.5 dB is obtained. In order to improve the bandwidth of the conventional patch antenna and split patch antenna, attention is given to both monopole and split-monopole antennas significantly. Due to which the input performances of the patch antenna has changed from frequency band 2.0 to 2.8 GHz to frequency band 2.0-7.0 GHz.

From the above literature review it can be seen that metamaterial can be used to enhance the antenna parameters by miniaturizing the antenna. Different types of metamaterials structure can be used to resonate at different frequencies. Defected and partial ground structure, slots in patch and ground can also be used for bandwidth and gain improvement. By the use of above discussion about antenna performance improvement, next chapter deals with the material and method and procedure of antenna design.

Materials and Methods

This chapter presents the basics of a microstrip patch antenna, feeding method, method of analysis, the equation used for designing the antenna, various antenna parameters, the methodology adopted, the software used, step by step procedure to design the proposed antenna, various optimization applied, fabrication steps and testing.

3.1 Microstrip patch antennas

The basic microstrip patch antenna has a single-layer design that consists of four general parts named as the radiating patch, the substrate, the ground plane, and the feed respectively is shown in Fig. 3.1. The radiating patch is a single element antenna that resonates at a certain resonant frequency. The ground plane has the same type of metal which is located on the opposite side of radiating patch on substrate.

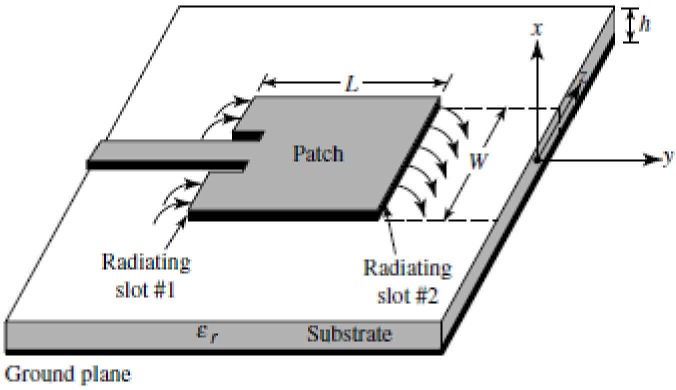


Figure 3.1 Basic microstrip patch antenna

The dielectric sheet separating both the radiating patch and the ground plane is known as the substrate, as shown in Fig. 3.2. The main purpose of the substrate layer is to provide proper spacing and to provide mechanical support between the patch and the ground plane

Figure 3.2 Side view of microstrip patch antenna

It is categorized on the basis of relative dielectric constant ε_r, having low insertion loss and loss tangent. The high value of dielectric constant material reduces the size of the radiating patch. The resonant frequency and bandwidth of the MSA are decided but the thickness of the substrate h. The increase in substrate height increases the bandwidth of the microstrip antenna till its limits, after which the antenna stops resonating.

3.2 Feeding Methods

There are various methods that are used for feeding a microstrip patch antenna. The most prominent methods are as follows:

1. Microstrip feed Line.
2. Coaxial Probe or coplanar feed.
3. Proximity Coupling.
4. Aperture Coupling.

While selecting the feeding method the most important point to be considered is that the maximum transfer of the power should take place which is possible only when proper impedance matching feed line and the radiating patch is there. Every feeding method has certain advantage and disadvantage which every designer has to kept in mind while designing the Patch antenna having good characteristics, good radiation parameter and efficiency because due to improper selection of feeding method total efficiency of the antenna will be reduced to a very low level making the system to get rejected.

Microstrip Line Feed

It is the most widely used feeding method due to its simple design and analysis, and very easy to manufacture properties. The microstrip line feed method has a conducting strip which is usually of smaller width in comparison to the width of the patch.

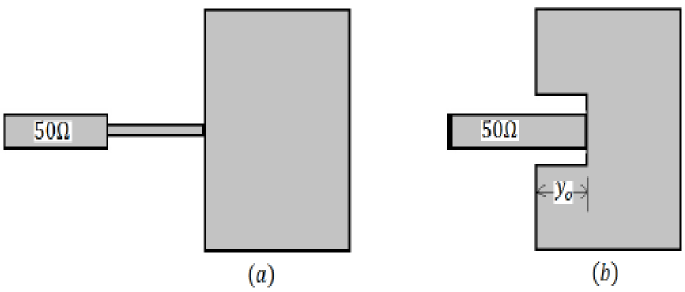


Figure 3.3 Microstrip patch antenna with Line Feed

Fig. 3.3 shows two configurations of a patch having a microstrip feed line method used for.

a) Inserted a quarter wavelength feed for proper impedance matching so that maximum transfer of power takes place.

b) Impedance matching is done by making an inset in the patch which can be controlled by the inset's dimension and its position.

3.3 Methods of Analysis

For the analysis of microstrip antennas, the most popular models are the transmission-line model, cavity model, and full-wave. The easiest among them is the transmission-line model as it gives the good physical insight of microstrip patch antenna, but it is less accurate and model coupling is more difficult, whereas the accurate cavity model is more complex while giving a good physical insight of antenna and is also difficult to the model coupling. The most widely used configuration of MSA is rectangular patch and is very easy to analyze using both transmission line model and cavity models (most accurate for thin substrates).

3.3.1 Transmission-Line Model

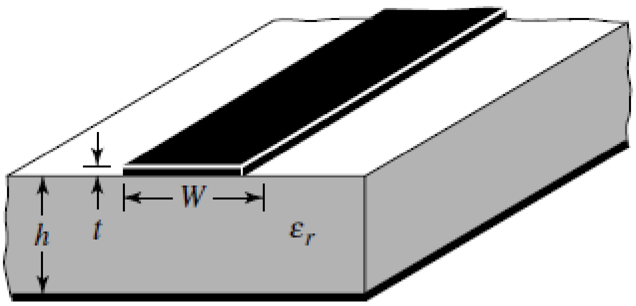
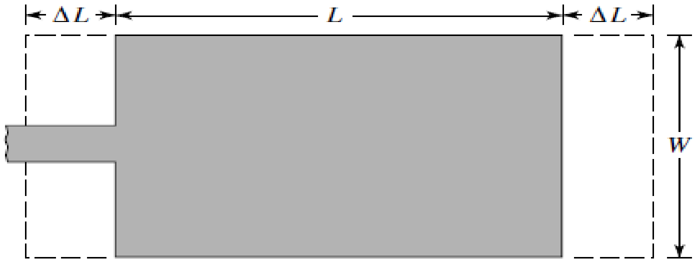
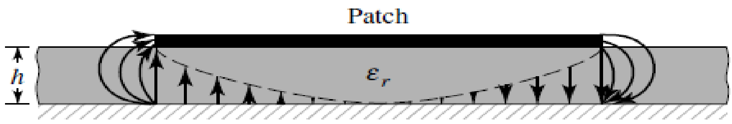


Figure 3.4 Microstrip Line

To study the rectangular microstrip patch antenna the transmission line model method is the easiest way; Fig.3.4 shows a transmission line model of a microstrip line. In the TLM model the first approximate assumption made is that there is no effect of the thickness of conductor (t) forming the line on calculations because in comparison to the substrate it is very thin, (h >> t); so only empirical formulas for calculating the dimensions are used. Fig. 3.5 shows physical dimensions like length L, width W and the height h for the microstrip patch made on the substrate with dielectric constant ε_r are calculated using the empirical formulas:



a) Top View



b) Side View

Figure 3.5 Physical and effective lengths of rectangular microstrip patch antenna

The characteristic impedance of a rectangular MSA is given by the equation:

$$Zo = \frac{120\pi}{\sqrt{\varepsilon_{reff}}\left\{1.393+\frac{W}{h}+\frac{2}{8}\ln\left(\frac{W}{h}+1.444\right)\right\}} \tag{3.1}$$

The width of the microstrip line is calculated by using the equation:

$$\mathrm{W}=\frac{1}{2\mathrm{f_r}\sqrt{\mu_o\,\varepsilon_o}}\sqrt{\frac{2}{\varepsilon_{r+1}}}=\frac{\nu_o}{2\mathrm{f_r}}\sqrt{\frac{2}{\varepsilon_{r+1}}} \tag{3.2}$$

The fringing effect has made the length of the patch of the microstrip patch antenna looks longer than its physical length. So the extension in length ΔL can be calculated by using the equation,

$$\frac{\Delta \mathrm{L_{eff}}}{\mathrm{h}}=0.412\,\frac{(\varepsilon_{\mathrm{reff}}+0.3)\left(\frac{\mathrm{W}}{\mathrm{h}}+0.264\right)}{(\varepsilon_{\mathrm{reff}}-0.258)\left(\frac{\mathrm{W}}{\mathrm{h}}+0.8\right)} \tag{3.3}$$

The effective length L_{eff} of the radiating patch after the extension of length ΔL is given by equation 3.5.

$$L_{eff} = (L + 2\Delta L_{eff}) \tag{3.4}$$

The resonant frequency for TM_{010} mode is given by:

$$(f_r)_{010} = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_o\,\varepsilon_o}} = \frac{\nu_o}{2L\sqrt{\varepsilon_r}} \tag{3.5}$$

Where the speed of light in free space is ν_o.

To calculate the effective dielectric constant, a consideration is made that radiating patch is implanted inside the dielectric as shown in Fig. 3.6

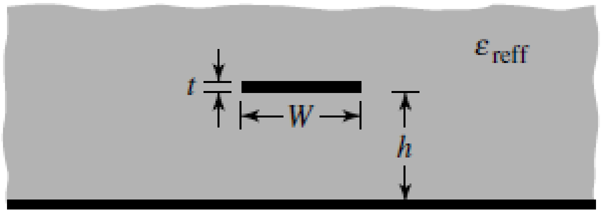


Figure 3.6 Effective dielectrics constant

For microstrip patch antennas with air above substrate the value of effective dielectric constant $1 < \varepsilon_{reff} < \varepsilon_r$. For $\varepsilon_r >> 1$, the actual value of dielectric constant ε_r is closer to the effective dielectric constant ε_{reff} of the substrate. The equation gives the resonant frequency f_r that can also be represented using the effective dielectric constant

$$f_r = \frac{\nu_o}{2\sqrt{\varepsilon_{reff}}\left(L+2\Delta L_{eff}\right)} \tag{3.6}$$

The formula used to calculate the effective dielectric constant ε_{reff} is given by equation 3.7:

$$\varepsilon_{reff} = \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_{r-1}}{2\sqrt{1+12\frac{h}{W}}} \tag{3.7}$$

The equation above helps to conclude that ε_{reff} the effective dielectric constant is a function of resonant frequency f_r, the height of substrate h, the width W of microstrip as well as the permittivity of the substrate ε_r **(Balanis,1997)**.

3.4 Antenna parameters

In order to characterize the performance of an antenna certain parameters are needed to be defined. According to the specification of the application, the antenna parameters are modified to values desired by different applications. Some of the essential parameters are :

Radiation patterns

The radiation pattern is generally expressed as the function of space coordinates. It consists of directivity, radiation intensity, and field strength. The normalized form of the power pattern and the field patterns with respect to their maximum value are generally drawn in the radiation patterns.

- The graphical representation of the magnitude of the far-field values i.e. **E** and **H** as a function of angular space are drawn as Field patterns.
- The graph of the square of the electric and magnetic field as a function of angular space is drawn as a Power pattern.

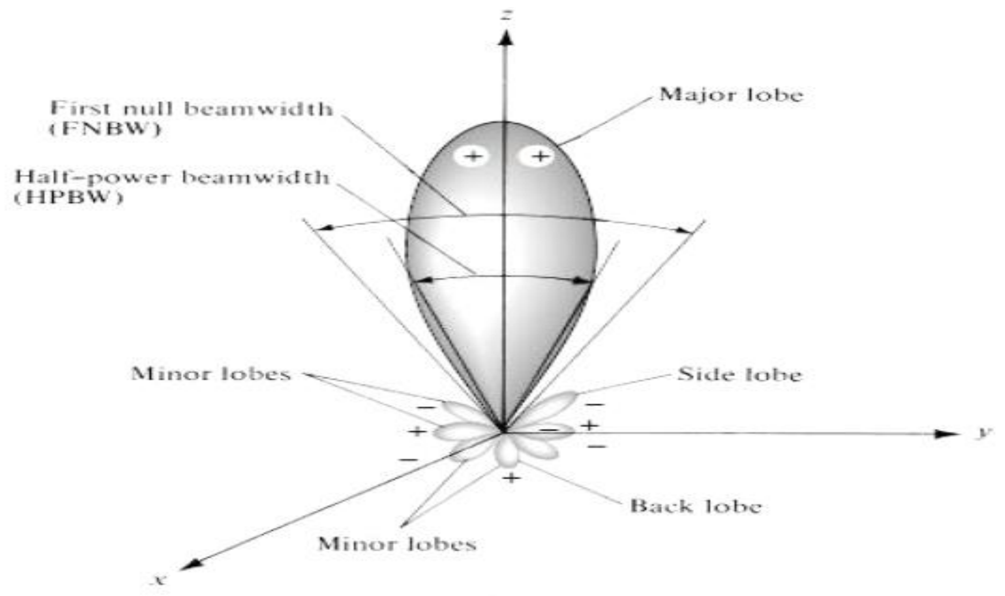


Figure 3.7 Antenna Radiation Pattern

Fig. 3.7 shows different parts of the radiation patterns, called as the lobes which are further divided into major lobe and minor lobe. The minor lobe consists of the Sidelobe and back lobe.

- The maximum part of the radiation is contained by the Major lobe.
- The radiation in undesired directions is termed as Minor lobes. It includes Side lobes and back lobes under it.
- The angular difference between the points where the field strength is 0.707 times of its maximum value and its power is 0.5 times the maximum value is called a half-power beamwidth (HPBW).

- The angular difference between the points where for the first time the field strength becomes zero in either direction is called as first null beamwidth (FNBW).

Return Loss

The amount of power reflected back by the antenna is referred to as a reflection coefficient which is given by the equation,

$$\Gamma = \frac{Z_A - Z_O}{Z_A + Z_O} \tag{3.8}$$

Where Z_A = the input impedance of transmitting antenna

Z_O = the characteristic impedance of the transmitting antenna.

The Magnitude of the reflection coefficient or S11 ranges between 0 to 1.

Return loss is given by equation:

$$\text{Return loss} = -20\log \Gamma \tag{3.9}$$

Voltage standing wave ratio (VSWR)

It is the ratio of maximum amplitude to the minimum amplitude of the standing wave. Mathematically the value of the VSWR depends on the magnitude of reflection coefficient:

$$\text{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{3.10}$$

The Range of VSWR is from 1 to ∞

- Perfect matching (VSWR = 1) No matching (VSWR ≠ 1)

Gain

The ratio of radiation intensity in a specified direction and the radiation intensity obtained in all directions if the equal input power is radiated gives the gain of the antenna

$$\text{Gain} = 4\pi \frac{\text{Radiation intensity}}{\text{Total input power}} \tag{3.11}$$

The measuring units for gain measurement are dB or dBi. When we use the isotropic radiator as reference antenna the dBi unit is used.

Bandwidth

The bandwidth of an antenna is the range of frequencies for which parameters like the reflection coefficient, radiation field patterns or the input impedance are within specified limits i.e. it should be less than -10 dB as shown in Fig. 3.8.

$$\text{Impedance Bandwidth} = \frac{f_u - f_l}{f_c} \times 100 \quad (3.12)$$

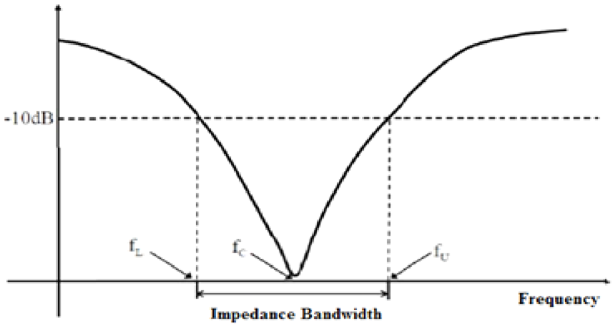


Figure 3.8 Bandwidth of an antenna

3.5 Ultra wide band technology

Ultra-wideband (UWB) is a radio transmission technology that occupies an extremely wide bandwidth exceeding the minimum of 500MHz or at least 20% of the center frequency. It is a revolutionary approach for the high-bandwidth short-range wireless communication. The UWB technology is differing from traditional narrowband radio systems (bandwidth usually less than 10% of center frequency) transmitting signals by modulating the amplitude, frequency or phase of the sinusoidal waveforms. The UWB systems transmit the information by generating radio energy at only specific instants of time in the form of very short pulses which occupying very large bandwidth and enabling the time modulation.

Due to the transmission of the non-successive and very short pulses, the UWB propagation will provide us a very high data rate which may reach up to several hundred megabytes per second, it is difficult to track the transmitting data making it highly secure for data transmission. For this same reason, consumption of the transmitting power in UWB systems is extremely low in comparison to that of traditional narrowband radio systems. Moreover, in UWB systems the transmitted short pulses of the reflected signal do not overlap with the original one hence help in avoiding the multipath fading. Because of these properties, the UWB technology is widely used in many applications like indoor positioning, radar/medical imaging, and the target sensor data collection. One of the challenges faced while the implementation of UWB systems is designing a suitable or optimal antenna.

The first and foremost important requirement which is to be fulfilled while designing a UWB antenna is the coverage of extremely wide impedance bandwidth. In 2002, the US FCC has allocated an unlicensed frequency band from 3.1GHz to 10.6GHz for UWB applications. Hence, up to 7.5GHz of bandwidth is covered by a workable UWB antenna. And the S_{11} for the entire ultra-wideband should be in the region of less than -10dB. For indoor wireless applications, the omnidirectional property of the radiation pattern is demanded UWB antenna to enable the convenience in communication between both transmitters and receivers. Therefore the uniform gain and low directivity are desired in all possible directions.

The radiation efficiency is also an important requirement while designing the UWB. Due to low power transmitted into space the high (normally the radiation efficiency should be no less than 70%) value of radiation efficiency is required. Last but not least the size of the UWB antennas is required to be sufficiently small so that they can be easily integrated into various equipment as the UWB technology is mainly employed for indoor and portable devices.

Due to huge operating bandwidth from 3.1 to 10.6 GHz, UWB systems are prone to interfere with existing narrowband communication systems that are IEEE802.11a (5.15–5.825 GHz) WLAN system and IEEE802.16 (3.3–3.8 GHz) WiMAX system. The external bandstop filter can be used with UWB antennas to mitigate interference issues, but it will make the overall system bulky and adds non-linearity to the system. So, UWB antennas with integrated band-rejection capability are preferred. The techniques are categorized broadly into two categories, (a) using resonant slots, (b) using parasitic resonators to the reference UWB antenna. In the former type, slots are either cutaway from the radiating element, embedded in the ground plane, or inserted in the feed-line itself. The later type consists of parasitic resonators placed close to the feed line or in the vicinity of the radiating element. The rejection band can be tuned by changing the dimensional parameters and location of these slots or parasitic resonators. All the above methods have their own pros and cons. When slots are used on the radiating element of the UWB antenna to create a notch, basically it creates destructive interference of the currents at a particular frequency. On the other hand, placing slots on the ground plane or on the feed line itself behaves as a pre-filter that creates a rejection in the UWB impedance bandwidth.

Using parasitic resonators also effectively creates a notch at the desired band. These techniques basically filter out the specific band from the UWB transmission, but it also adds some undesirable effects in the time domain as well as in frequency domain behavior of the UWB system. These slots and parasitic elements behave as resonant type band-reject filters and filters a specific spectral component and hold the energy so that the UWB antenna ceases to transmit or receive at that frequency. However, these are low Q-filters and can't hold the energy for a longer time. Eventually, the stored energy decays in the form of spurious radiation or losses. This affects the transient behavior of the antenna and causes a prolonged ringing effect on the transmitted pulse in the time domain.

3.6 Defected Ground Structures (DGS) (A. K. Arya *et al.*, 2010)

Defected ground structure (DGS) increases the overall performance of the system by intentionally altering the metallic ground plane of the microstrip antenna. It is analyzed by deliberately etching out a normal shape of the ground plane which is known as "defect or fault". These defects interrupt the shielded current distribution in the ground plane, leading to the propagation of electromagnetic (EM) waves in the layers of the substrate. The shape of the defect may change from simple one to the complex shape for better performance of the systems. Single or multiple defects in the ground plane can be made. The defected surfaces are used to suppress the mutual coupling between the elements and also to decrease the harmonics. Nowadays researchers are working on DGS in antenna applications for improving, the bandwidth, size reduction, multi-band applications, and polarization. The DGS is also capable of improving the level of the return loss .as this is a good field for research work, the technology has been deployed in microstrip antennas in different shapes for various applications. The various shapes of DGS structures that are possible are rectangular, square, circular shape, dumbbell shape, spiral, L-shaped, concentric ring, U-shaped, hairpin DGS, hexagonal DGS, and combined structures have been seen in the various literature. These structures can also use in periodic form. DGS has various advantages in the area microstrip antennas as it leads to improving the bandwidth, return loss, size reduction and polarization.

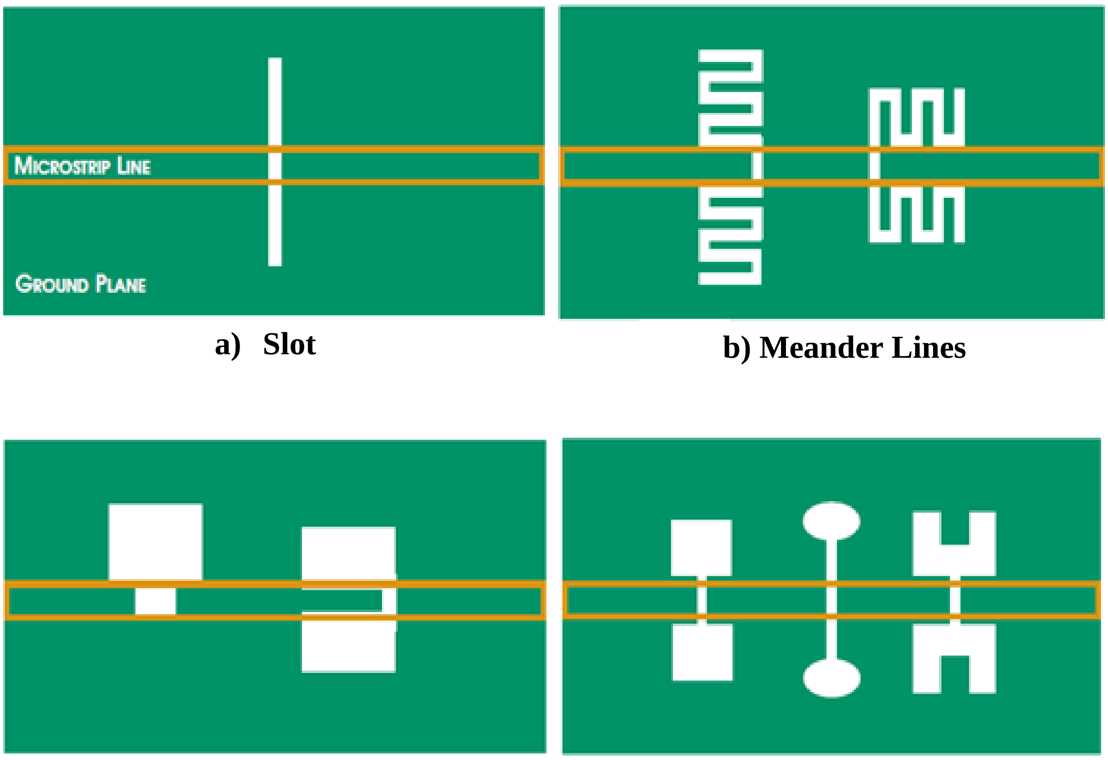
Characteristics of DGS Element

The Defected Ground Structure (DGS) is achieved by simply etching a shape from a ground plane called a defect on the plane of the ground. This defected pattern has an effect on the current distribution of microstrip in the ground plane. The defected ground structure has changed the characteristics like transmission line capacitance, inductance and resistance and has enhanced the performance of the antenna. The two effects that have been created in the ground plane are band-stop property and the slow-wave effect.

The most basic element of DGS consist of a slotted hole in the ground plane of the microstrip antenna, which is located just below the transmission line, this slot is made for proficient coupling to the microstrip line. Depending on the application a suitable structure is selected and leads to optimization of antenna performance. Some of the commonly used DGS shapes are:

- Slot structure
- Meander lines structure
- Slot variations structure
- Various dumbbell shapes

In the slot or slit type structure, the location of the defected shape is just beneath the line used for transportation of energy to patch. The slot basically creates a resonant circuit. Different types of shapes can be used pertaining to resonance provided. The shape, size, and position of the slot decide the performance of the microstrip antenna. The meander lines structure can have a zig-zag shape made on the metallic ground plane positioned just beneath the feed line which is used for transmission of energy. The slot variations type structure has the variations in the slot known as defected ground structure. The above mentioned resonant structure is shown in Fig. 3.9.



a) Slot

b) Meander Lines

c) Slot variations

d) Various Dumbbell shape

Figure 3.9 Different shapes of DGS

The equivalent circuit of DGS has a parallel tuned circuit which is always in the series with a coupled transmission line. The dimensions and position of the DGS will decide the equivalent values of inductance, capacitance, and resistances. Due to this DGS effect on resistance, capacitance, and inductance the characteristics of the microstrip antenna also improves.

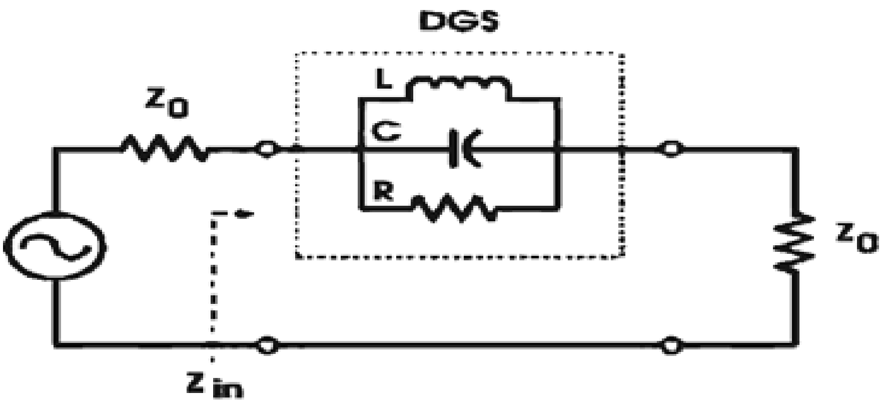


Figure 3.10 Equivalent circuit of DGS element

Fig. 3.10 shows the equivalent circuit of DGS consisting of a parallel tuned type circuit in series with the microstrip line to which it is coupled. The parameters like input (Z_{in}) and output impedance (Z_o) of the transmission line are calculated on the line section, whereas the corresponding values of inductance, capacitance and resistance are decided by the dimensions and location of structures of the DGS. In Fig. 3.10 the source is at the transmitting side to provide the energy to the transmission line and the load at the receiving side. The input impedance, output impedance and also characteristics impedance are mentioned in diagram.

The defected ground structure used for microwave antenna design has numerous applications like

- Enhancement of radiation properties
- Reduction in antenna size
- reduction of harmonic frequency
- reduction in cross-polarization radiation
- mutual coupling reduction in microstrip antenna arrays
- Broadband RCS reduction

In spite of making slots inside the ground plane, in the proposed work the slot is made on edge of the ground and the corners are tapered to improve the operating bandwidth.

3.7 HFSS Software

The design or simulation of an antenna can be done on various types of software, among that various software a high-frequency structure simulator (HFSS) software is widely used for research purposes. HFSS which is basically used for analysis and design of electromagnetic component uses the finite element method (FEM) numerical technique. The method is generally developed to obtain a solution to the structural analysis and elasticity problem of aeronautical engineering. The values of electric and magnetic fields in HFSS are calculated using the below-mentioned equations.

$$\nabla \times \left(\frac{1}{\mu_r} \nabla \times \vec{E}\right) - k^2 \varepsilon_r \vec{E} = 0 \qquad (3.12)$$

$$\vec{H} = \frac{j}{\omega\mu} \nabla \times \vec{E} \qquad (3.13)$$

The tetrahedron is the basic mesh element in HFSS. The Maxwell's equations for electromagnetic field theory are applied to get the solution at each node point of the tetrahedron. Thus any 3D geometry problem can be easily solved in a negligible amount of time. The ANSYS made HFSS can be used to calculate the parameters like the gain, resonant frequency, radiation fields, and various S-parameters. In HFSS the 3D model of any electromagnetic element can be easily designed according to requirements of the user and one can deduce the parameters for the designed structure. The main steps to design and simulate the results are.

1. Create a 3D model
2. Assign Boundaries to patch and ground
3. Assign excitation to feed point
4. Set the solution set up
5. Analysis and Validation of the designed model
6. Results are calculated

Create 3D model

During the designing of an antenna, the first step to be taken is to create a model according to the needed dimension of the substrate, radiating patch, and the ground plane. The parametric analysis is applied to 3D model for different parameters on their size; it allows the user to change the geometrical dimensions of the structure and also a property of used material. And by changing the parameters optimized results are obtained. A model like driven model, driven terminal, Eigenmode is used to obtain different solutions. The driven model gives the model-based Scattering parameter(S-parameters) of the high-frequency passive structures. To get the S-parameters based on the terminal, driven terminal mode is used. The S-parameter can be obtained for the transmission line ports having single and multi-conductors. To calculate value of resonance of structure the Eigenmode is used.

Boundary assign

After creating the 3D model of the electromagnetic structure, boundaries like perfect E, perfect H, finite conductivity and radiation, etc. are applied to patch, ground and radiation box. For microstrip antenna, the radiating patch and the ground planes are assigned with finite conductivity or perfect E and the radiation box is assigned with the radiation. The assigned boundary has a direct impact on the solution obtained on HFSS.

Excitation assign

The excitation used for the MSA has a direct impact on the quality of results. In the case of antenna designed either of wave port or the lumped port is given as excitation. For the external boundary wave port is used whereas for internal boundary lumped port is used.

Solution set-up

For setting up the solution set-up in HFSS, a frequency is selected for desired results which the user wants. For the frequency band over which the results are required, a maximum number of the frequency sweep and adaptive passes are selected.

Validation and analysis of model

The validation of design and its analysis is required to check the errors if any present. The geometry of the model will decide the time required in the analysis of the model. Other factors are also responsible for it as the solution frequency, a number of sweeps, the step size, etc.

Results

After executing the above-mentioned design steps, the parameters like return loss (S_{11}), VSWR, antenna gain, antenna directivity, the radiation pattern, etc. for the designed antenna can be obtained.

3.8 Designing of Proposed Antenna

This section involves the designing steps, different parametric variations involved in the design, their simulation processes, optimization of different antenna parameters, fabrication process on PCB designing machine and measurement process of the proposed antenna using vector network analyzer (VNA).

3.8.1 Development of the proposed antenna

An Ultra wide band microstrip antenna with microstrip line feed having controllable notch characteristics is presented in the proposed research work. Initially, the proposed antenna is designed to operate over the frequency band given by FCC from 3.1 to 10.6 GHz for wireless applications. Primarily, the conventional monopole antenna is designed using the TLM model and then its optimization is done in terms of various dimensional parameters using HFSS. The fabrication of the proposed antenna is done by using the PCB prototype machine (EP 2002) and the measurement of the various antenna parameters is done with the help of VNA (Vector Network Analyzer).

In the first stage of the design, a conventional rectangular monopole microstrip antenna is made and then the optimization is done on the dimensions of the patch and feed line. In the next step tapering of the patch is done on edges to improve the bandwidth and gain. In the second stage of the design, the cuts on the ground are made with the help of the Defected Ground Structure to improve the bandwidth and gain of the proposed antenna. The proposed antenna has used FR4 epoxy as the dielectric substrate of thickness 1.6 mm with dielectric constant of 4.4 and loss tangent of substrate material 0.02.

After stage two is completed, we have obtained the band from 3.1 to 16.8 GHz. In the third stage of the design, with the use of two slot structures, one in the patch and one in feed, the notching characteristics are obtained. The notching helps to remove the interference due to already existing frequency band applications like WLAN and WiMAX.

3.8.2 Designing of conventional monopole antenna and its miniaturization.

Initially, a conventional rectangular monopole antenna is designed for the resonant frequency at 4.25 GHz. All the calculations of the dimensions are carried out using the TLM model. The length 'Lp' and width 'Wp' of the rectangular patch is found to be 14.5 mm and 15 mm, respectively. For feeding the microstrip patch, shifted line feed is used. For the conventional monopole patch antenna, the substrate has the dimensions of Ls =35 mm and Ws = 30 mm. The basic monopole antenna is designed which operates on a frequency band from 3.3 GHz to 10.6 GHz. Fig.3.11 and Fig.3.12 show the geometry of conventional monopole antenna and the reflection coefficient of simple monopole patch respectively.

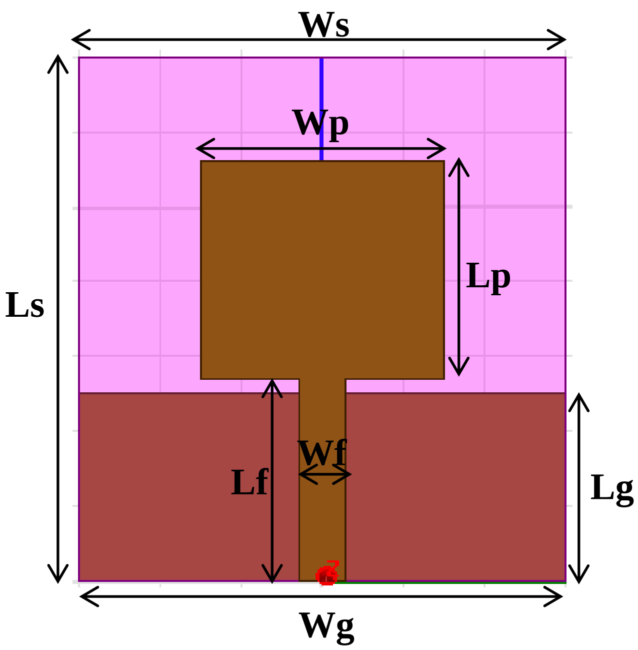


Figure 3.11 Basic monopole antenna

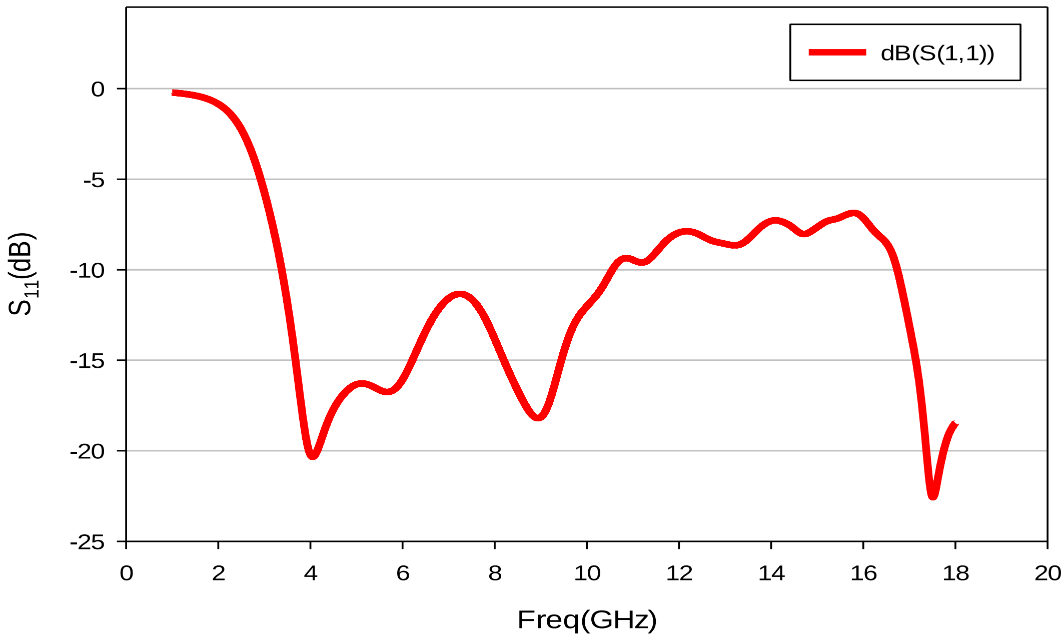


Figure 3.12 Return loss for basic monopole antenna

The Fig.3.13 shows that conventional monopole antenna has the value of VSWR less than 2 over the entire operating band and the peak gain of the simple monopole patch antenna is shown in Fig. 3.14.

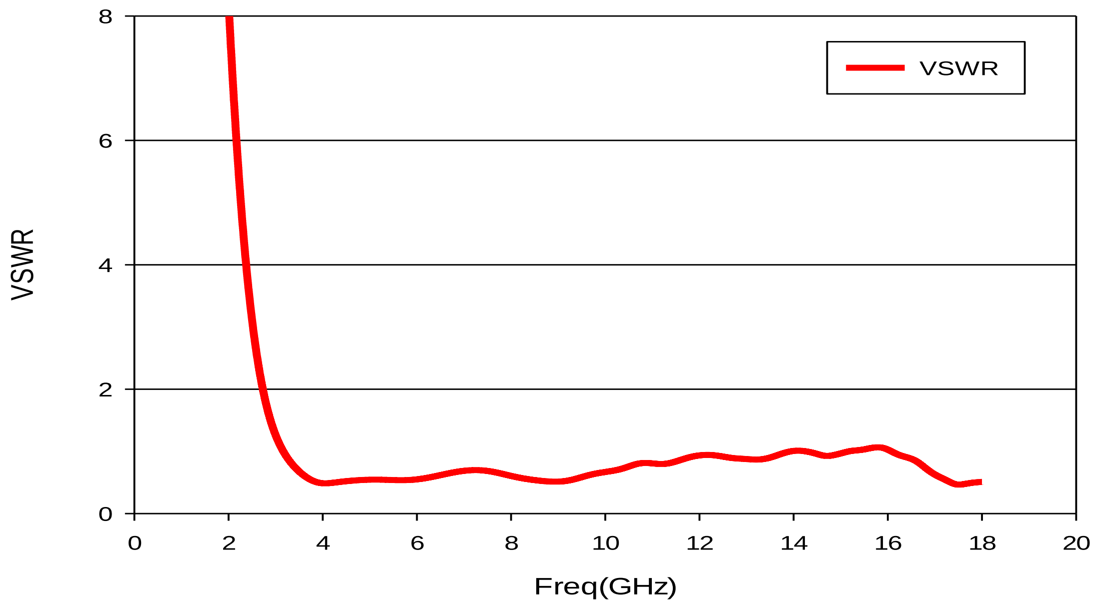


Figure 3.13 VSWR for basic monopole antenna

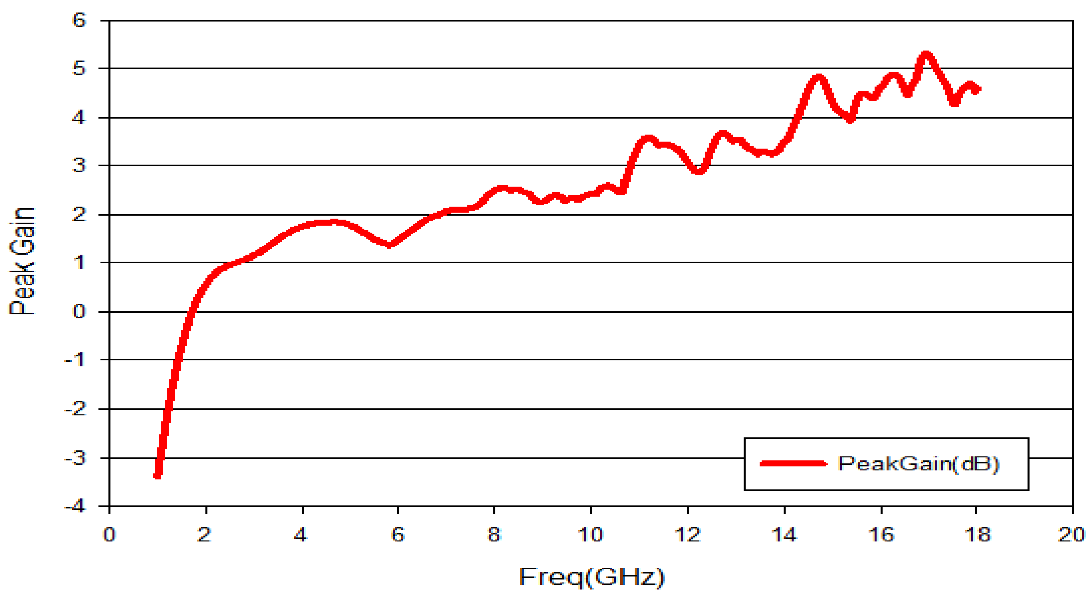


Figure 3.14 Peak gain for basic monopole antenna

After designing the basic monopole patch antenna, the optimization of the feed line is done to improve the operating bandwidth. The parameters of the feed line which are used for the optimization purpose are the length of the feed line, width of feed line and the position of the feed line. First the length of feed line is optimized from value Lf=13.5 mm to 14.5 mm with a step size of 0.1 mm and from Fig. 3.15 it is seen that for the optimized value of Lf=14.1 mm the better reflection coefficient of -49.5 dB at near about center frequency and the operating bandwidth from 3.2 to 9.6 GHz is obtained.

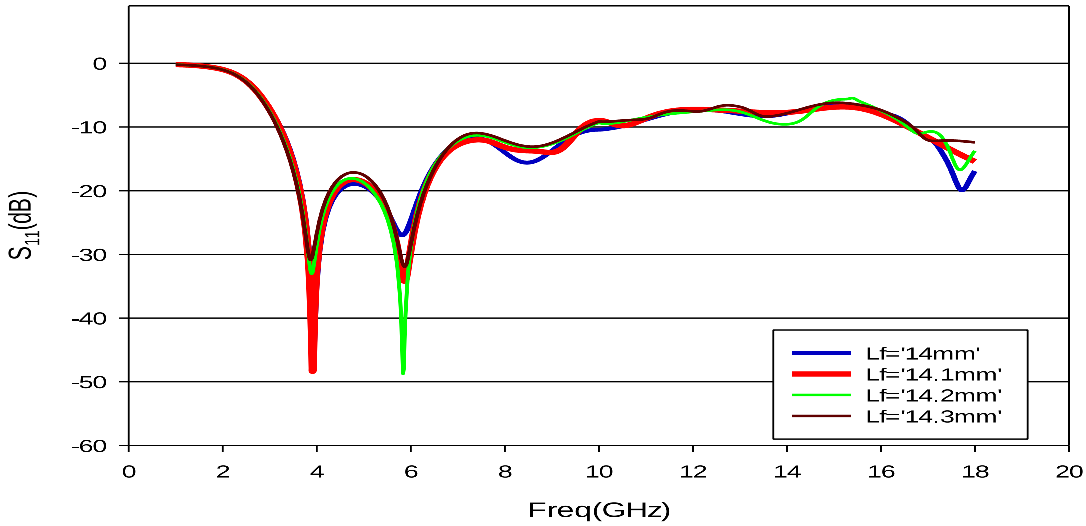


Figure 3.15 Parametric analysis on length of feed

Secondly, for the parametric study of the width of the feed, the value is varied from 2.9 mm to 3.2 mm with step of 0.05 mm. Fig.3.16 shows shift in operating band due to variation in width of feed line and for the selected optimized value of Wf=3.05 mm, the reflection coefficient of -52 dB is obtained and the operating bandwidth is from 3.1 to 9.6 GHz. The Fig.3.17 shows the basic monopole antenna after optimization on feed is applied.

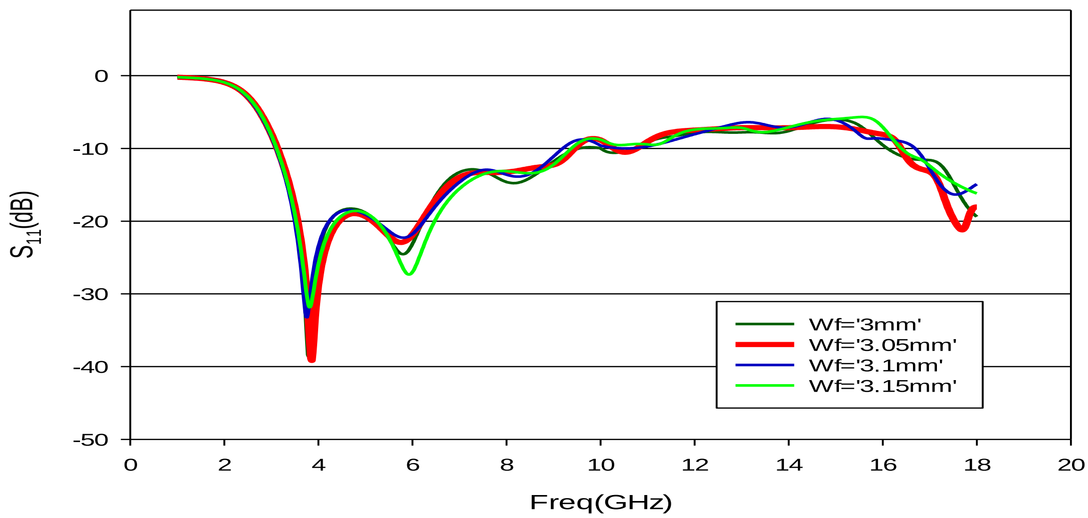


Figure 3.16 Parametric analysis on width of feed

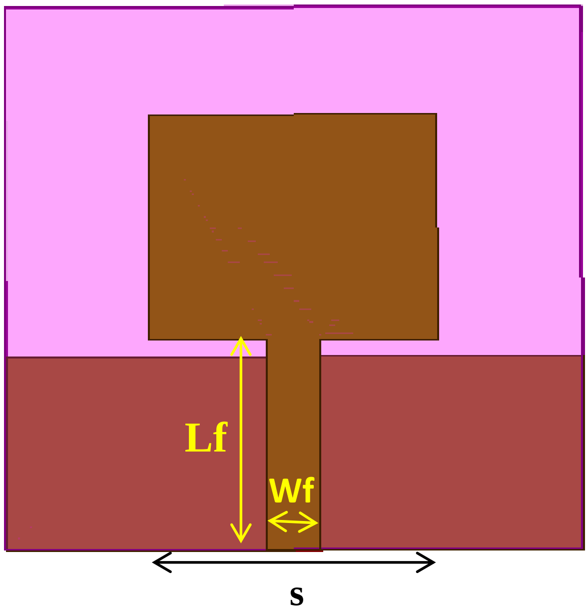


Figure 3.17 Basic monopole antenna after optimisation on feed

Table 3.1 Dimensions of the basic monopole antenna

Parameters	Length (mm)	Parameters	Length(mm)
Ws	30.0	Wp	15.0
Ls	35.0	Lp	14.5
Wg	30.0	Lf	14.1
Lg	12.5	Wf	3.05

Table 3.1 gives the dimensions of the basic monopole antenna. Then the parametric study on the position of the feed line is performed, the microstrip feed line is moved from centre position to the edges of the patch and from the parametric study plot in Fig. 3.18, it is seen that for optimized value of s=1.8 mm, the reflection coefficient of -21.9 dB and -33.2 dB is obtained at resonating frequencies 3.8 GHz and 6.25 GHz respectively. The operating bandwidth has also shown an increase from 3.0 to 10.04 GHz.

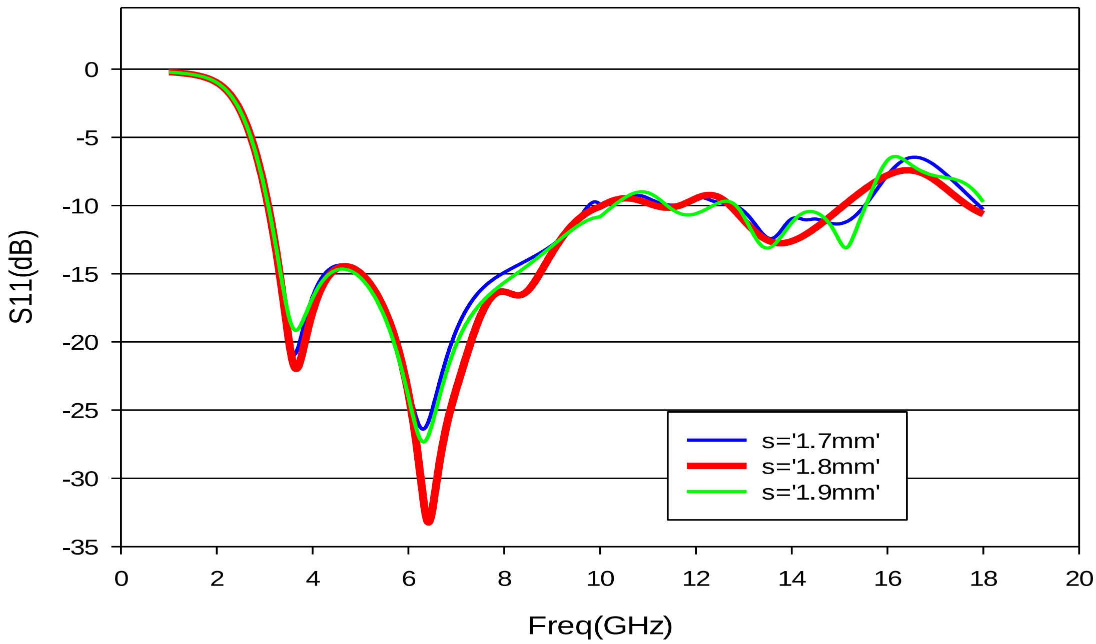


Figure 3.18 Parametric analysis on position of feed line

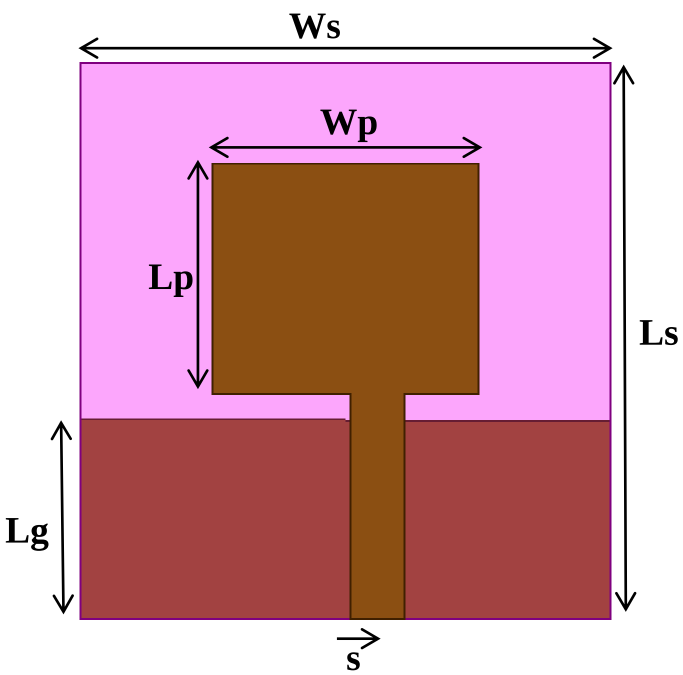


Figure 3.19 Proposed antenna after optimisation applied

After applying all the optimized parameters on the feed line we get the proposed antenna as shown in Fig.3.19, the edges of the patch are tapered and their parametric analysis is performed. Firstly the upper two edges of the rectangular patch are tapered in a circular shape as shown in Fig. 3.20. For the parametric analysis applied in terms of radius of tapered portion; the value is varied from 1 mm to 2 mm with a step size of 0.1 mm. Fig. 3.21 shows the return loss obtained after parametric analysis is done, from those values the r=1.4 mm is selected which has operating frequency region of 3.1 to 10.3 GHz with return loss of -20.5 and -28.5 dB at 3.6 and 6.4 GHz.

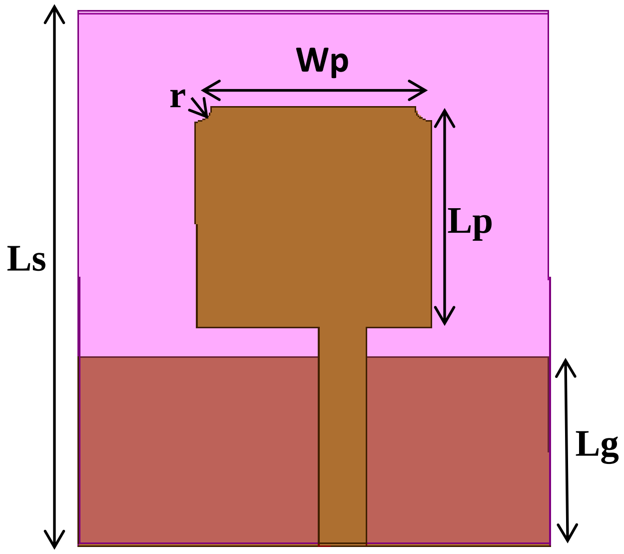


Figure 3.20 Proposed antenna after circular edge tapered

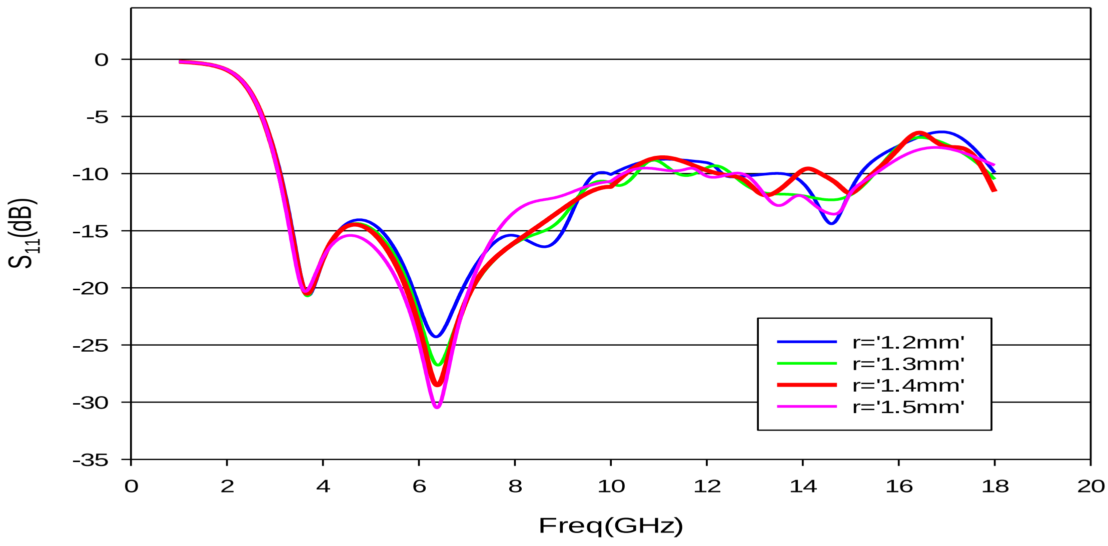


Figure 3.21 Parametric analysis on radius of circular edge tapered

After applying optimised result for circular edge tapering, the lower two edges are tapered in shape of stair to improve the operating bandwidth of the antenna as shown in Fig. 3.22. The parametric analysis of this stair shape tapering is done in two ways, the length and the width of the stair are varied. First, the width of the stair is varied from 0.8 mm to 1.5mm with a step size of 0.1 mm. Among all the values of x in parametric analysis shown in Fig. 3.23, the x=1 mm is selected as it has increased the operating frequency region of 3.1 to 10.8 GHz.

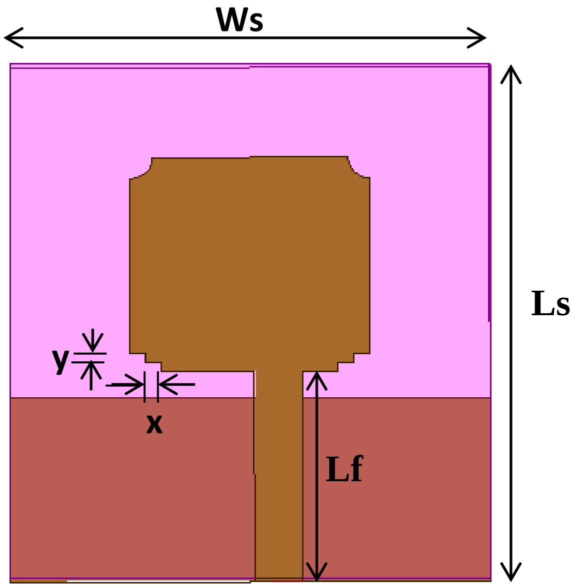


Figure 3.22 Proposed antenna after stair-case edge tapered

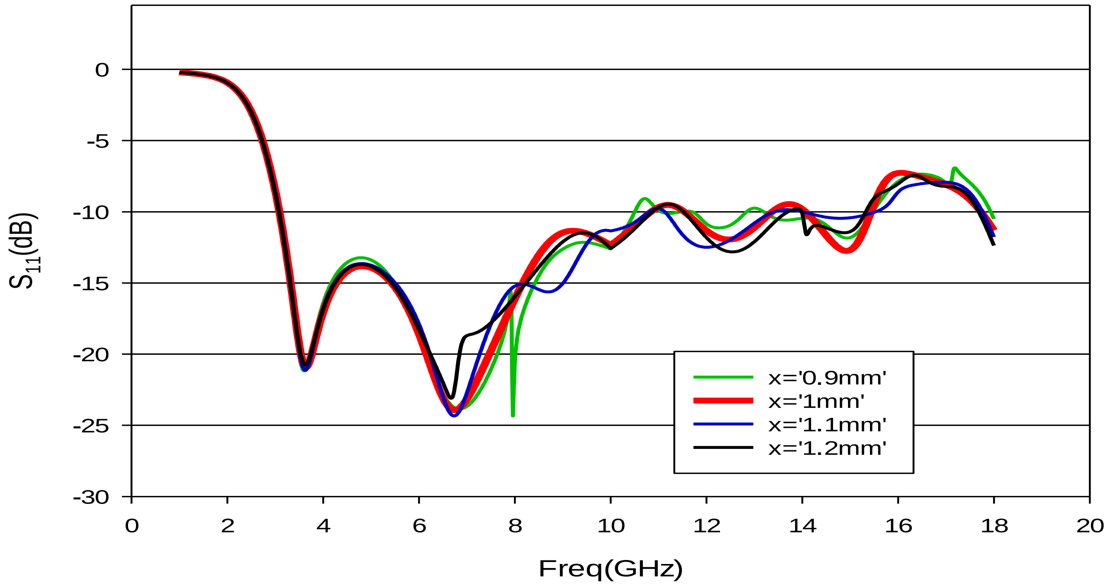


Figure 3.23 Parametric analysis on width of stair-case edge tapered

Fig. 3.24 shows the parametric analysis on the length of the stair-case tapering made on edge of the patch. In this analysis the length of the stair is varied from 0.4 mm to 1 mm with step size of 0.1 mm. Among all the values of y in parametric analysis, y=0.6 mm is selected which has increased the operating frequency region of 3.1 to 10.9 GHz. Also the return loss of -21 dB and -24 dB is obtained at 3.6 GHz and 6.8 GHz, respectively.

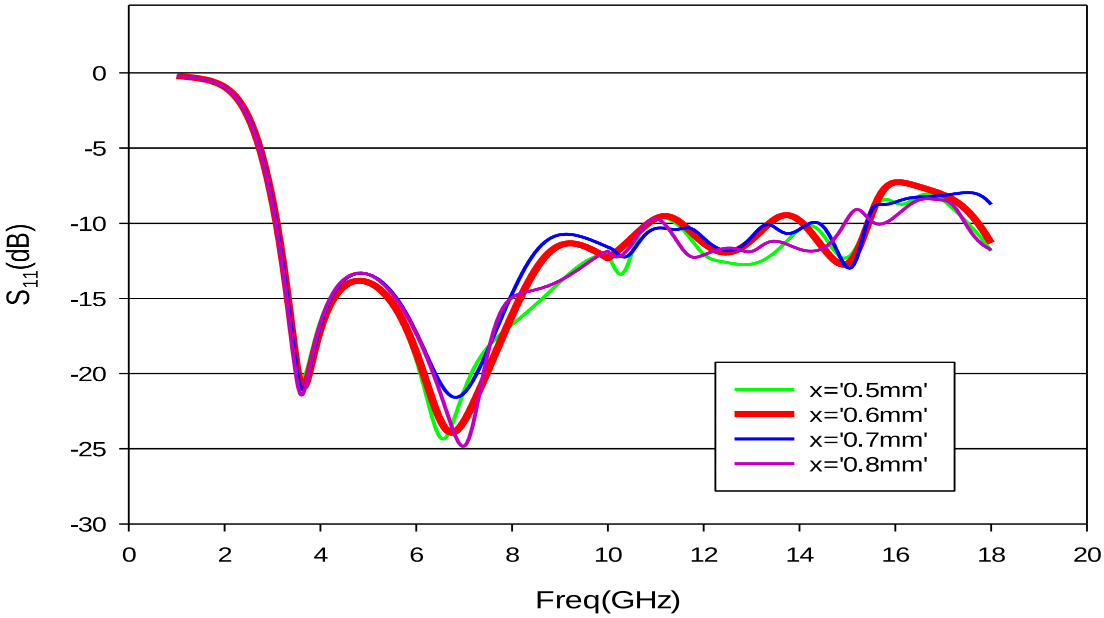


Figure 3.24 Parametric analysis on length of stair-case edge tapered

In the end, the application of all optimized values has made various changes on the patch and gives the antenna shown in Fig.3.25. Fig 3.26 shows the return loss and Fig. 3.27 shows the VSWR for the basic microstrip monopole antenna. The operating frequency band is from 3.07 to 10.81 GHz with bandwidth of 7.74 GHz and at 3.6 GHz and 6.7 GHz, the return loss of -20.27 dB and -23.82 dB is obtained. For the entire operating band the value of VSWR is always less than 2.

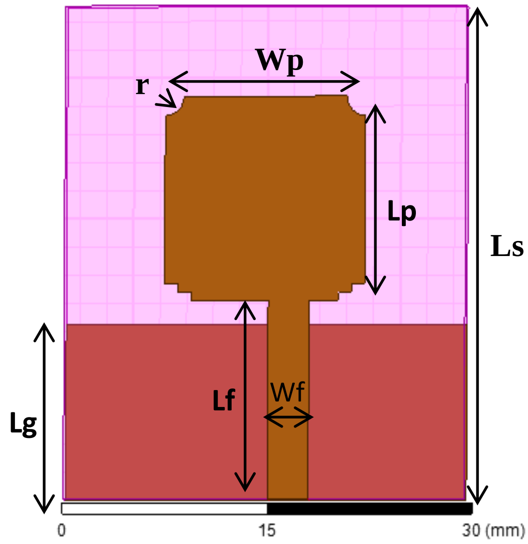


Figure 3.25 Proposed antenna after first stage

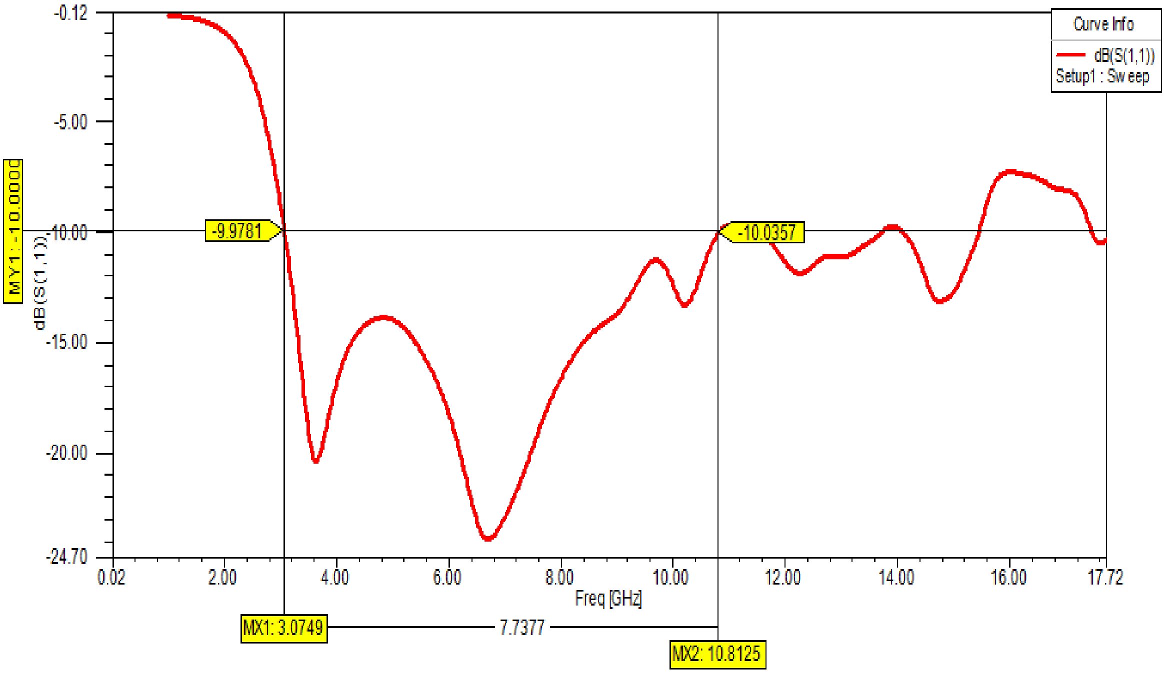


Figure 3.26 Return Loss of proposed antenna after first stage

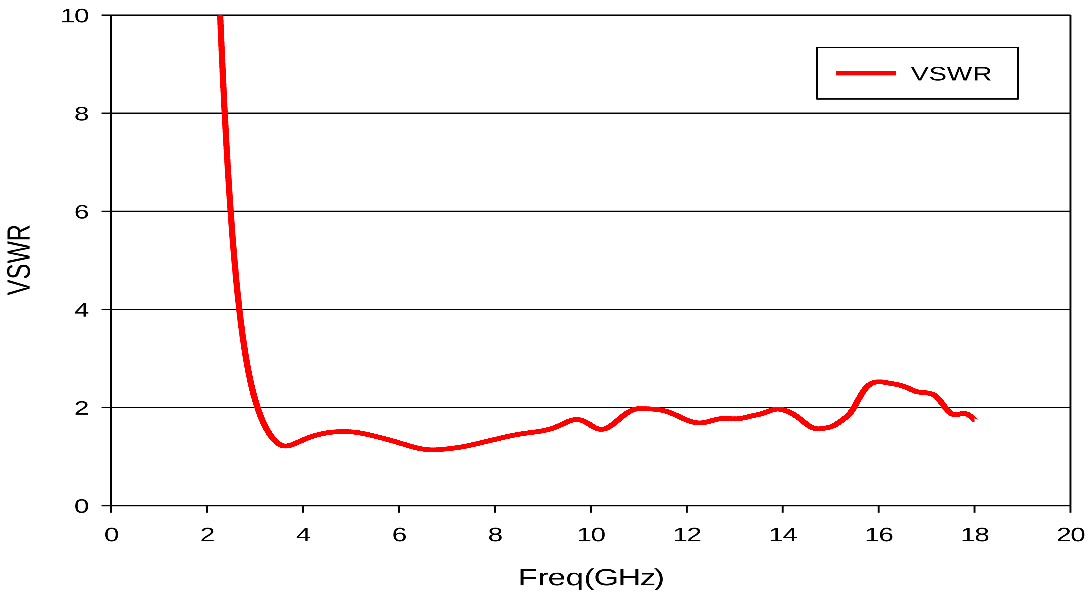


Figure 3.27 VSWR of proposed antenna after first stage

The monopole antenna has a peak gain of 3.34 dB at 4.25 GHz frequency and reached more than 10 dB for higher frequencies as shown in Fig. 3.28.

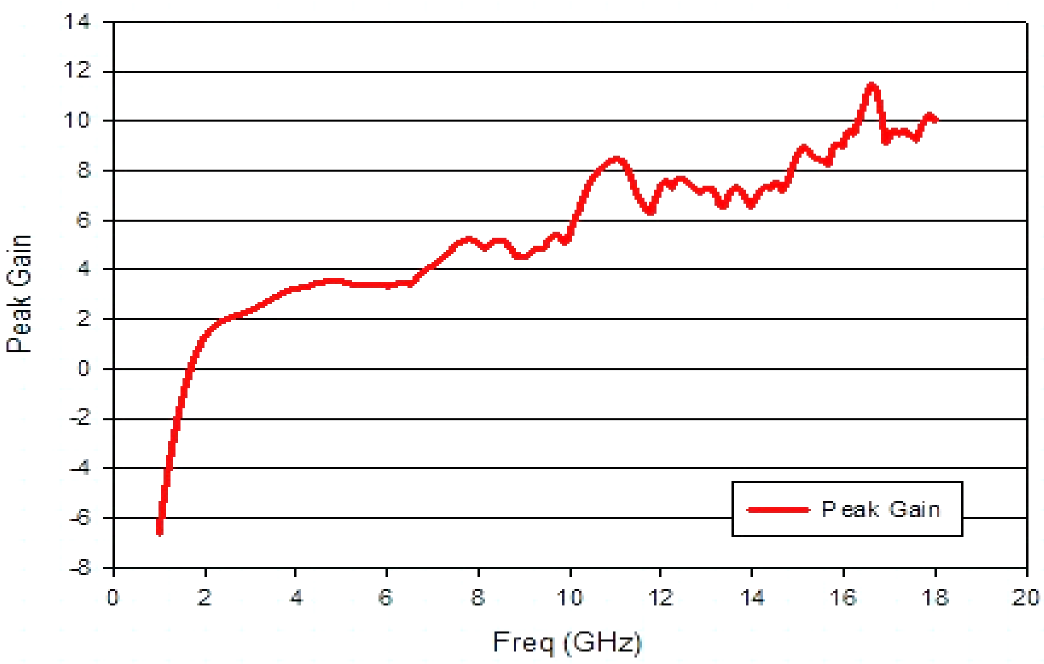


Figure 3.28 Peak Gain of proposed antenna after first stage

Fig. 3.29 shows the 3D Polar plot and 2D radiation pattern at 4.25 GHz frequency

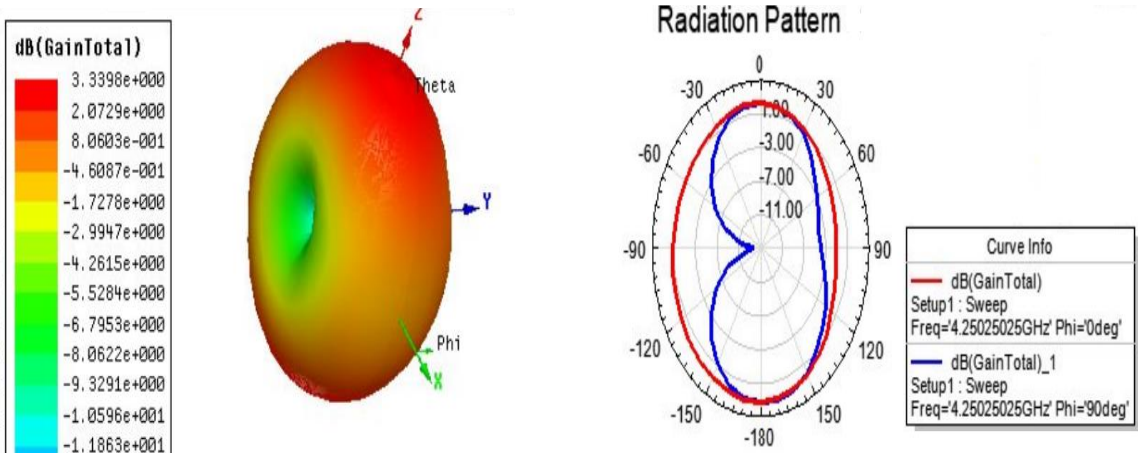


Figure 3.29 3D Polar plot and 2D radiation pattern

3.8.3 Designing of monopole antenna with modified ground structure.

Now the various steps are applied to modify the ground plane along with its parametric analysis. To increases the performance of the monopole antenna the ground of the antenna is deliberately altered by removing a certain portion of the ground plane. After applying the parametric analysis on the length of the ground plane to make it a monopole antenna, the length and the width of the ground Lg = 12.5 mm and Wg=30 mm is selected. The partial ground is modified to a different shape by removing a rectangular slot and edges of the ground are tapered in a circular shape. First, the rectangular slot is etched out of the ground as shown by Fig. 3.30, and parametric analysis is performed on the slot in terms of its length, width and position.

The parametric analysis on the length of the rectangular slot, 'l' in-ground is shown by Fig. 3.31, the parameter is varied from 2 mm to 2.5 mm with a step size of 0.1 mm. Among all the values 'l', l=2.3 mm is selected as it has shown improved operating frequency range. The operating band has started at 3.1 GHz and goes beyond 18 GHz.

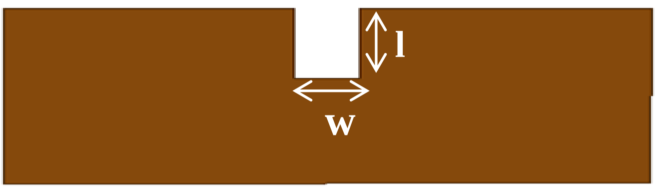


Figure 3.30 Modified ground plane

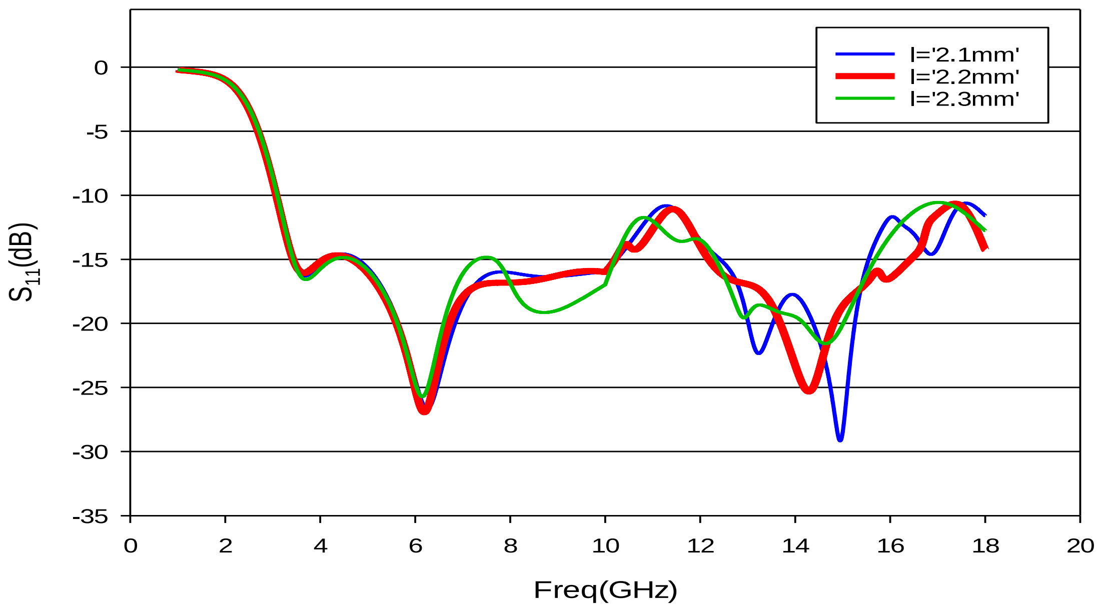


Figure 3.31 Parametric analysis on length of rectangular cut in ground plane

Afterward the parametric analysis on the width of rectangular slot 'w' is performed, shown by Fig 3.32, the parameter is varied from 1.8 mm to 2.5 mm with step size of 0.1mm.Among all these values, w=2 mm is selected as it has shown improved return loss characteristics at lower frequencies. The operating band has started at 3.1 GHz and goes up to 17.1 GHz.

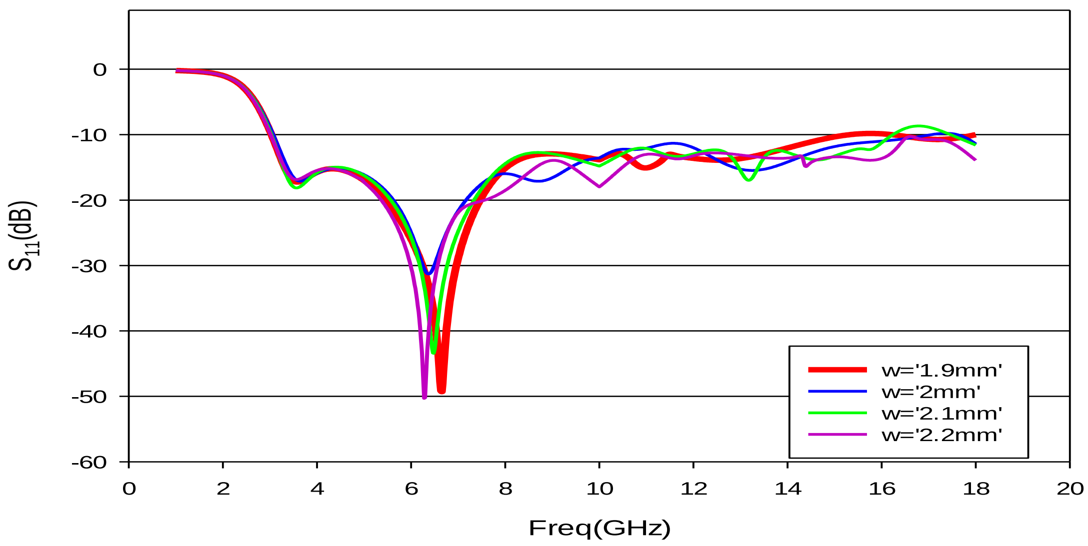


Figure 3.32 Parametric analysis on width of rectangular cut in ground plane

After applying the optimal results of the length and width of the slot etched out in-ground, the position of the slot is optimized for improving the results. The position of the rectangular slot in the ground is shifted from center position to both sides of the ground plane. Among all those values of shift in Fig.3.34, the sh= 1.8 mm is selected as it has shifted the return loss characteristics again to the operating band which has started from 3.1 GHz and goes beyond 18 GHz and the shifted slot is shown in Fig.3.33.

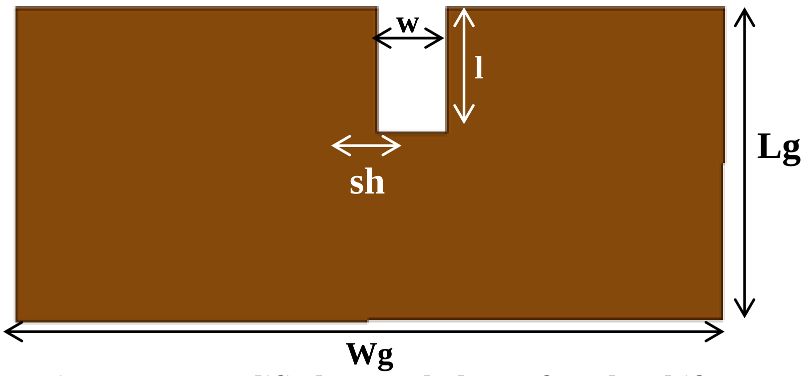


Figure 3.33 Modified ground plane after slot shift

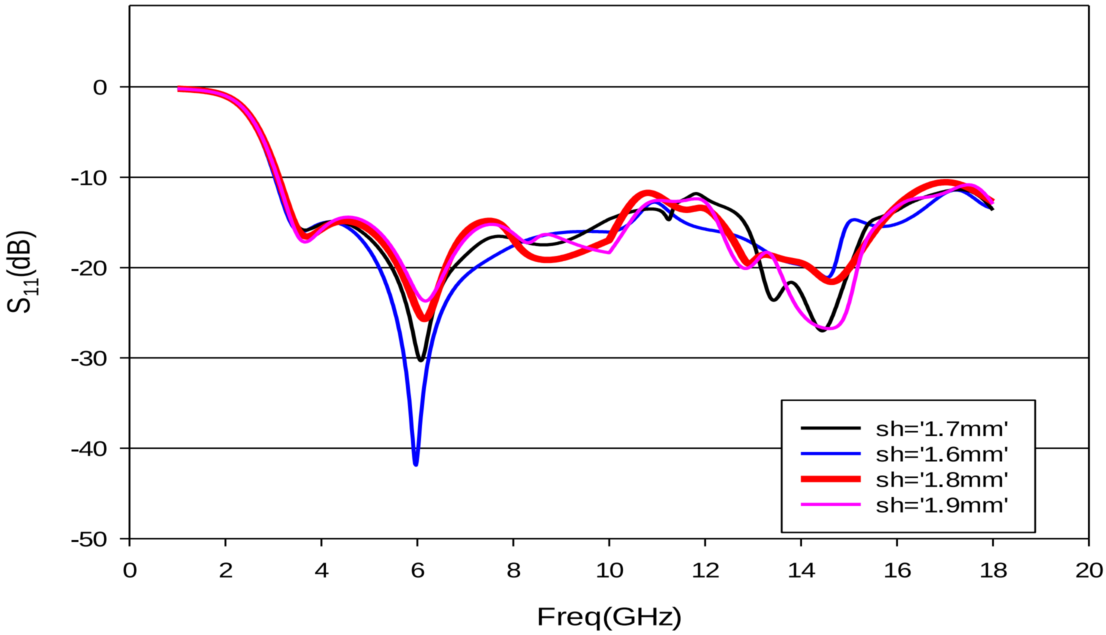


Figure 3.34 Parametric analysis on shift in position of slot in ground plane

After the rectangular slot etched out of the ground plane, the edges of the ground are tapered in circular shape as shown in Fig. 3.35. The parametric analysis is performed on this circular shape tapering on y-axis while fixing the x-axis value at a=4 mm. Fig 3.36

shows the parametric analysis on tapering, by shifting it on y-axis from 2 mm to 8 mm with a step size of 1 mm. The b=6 mm is selected out of these values as it has shown improved value of the return loss characteristics. The effect it has on operating band which has started at 3.1 GHz and goes beyond 18 GHz is negligible.

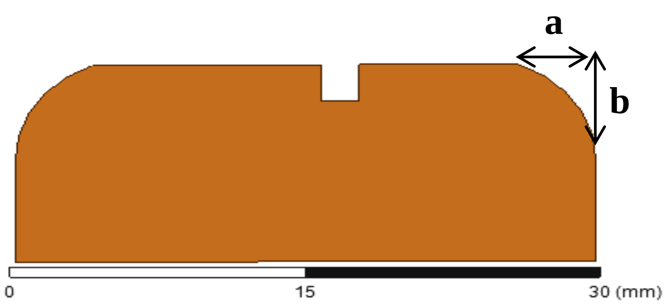


Figure 3.35 Modified ground plane after circular shape tapering

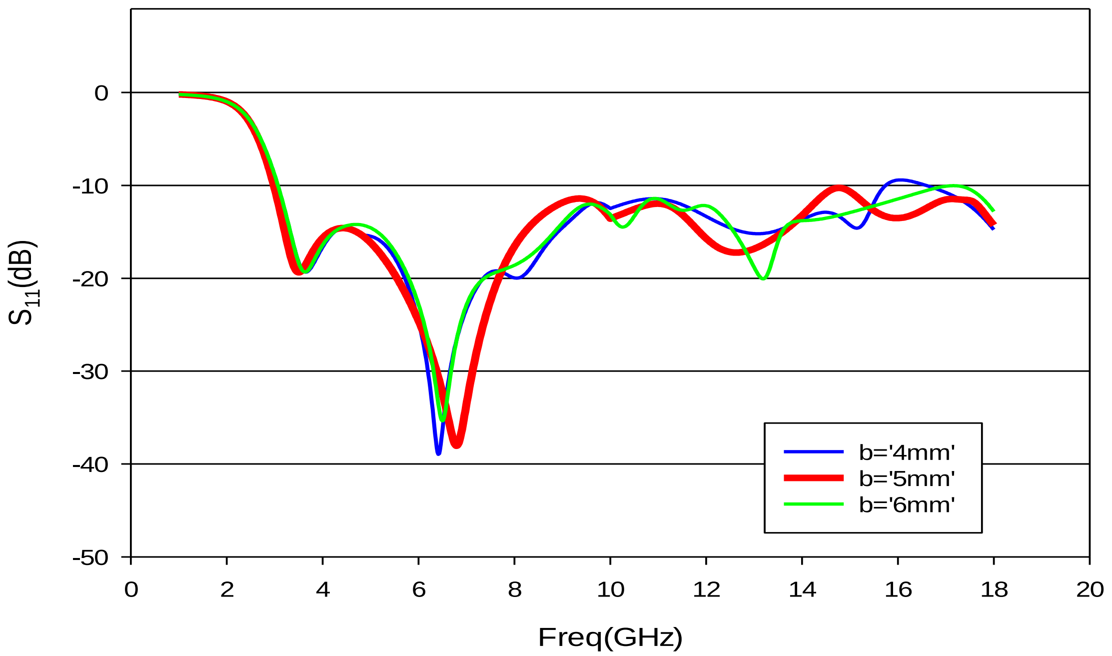
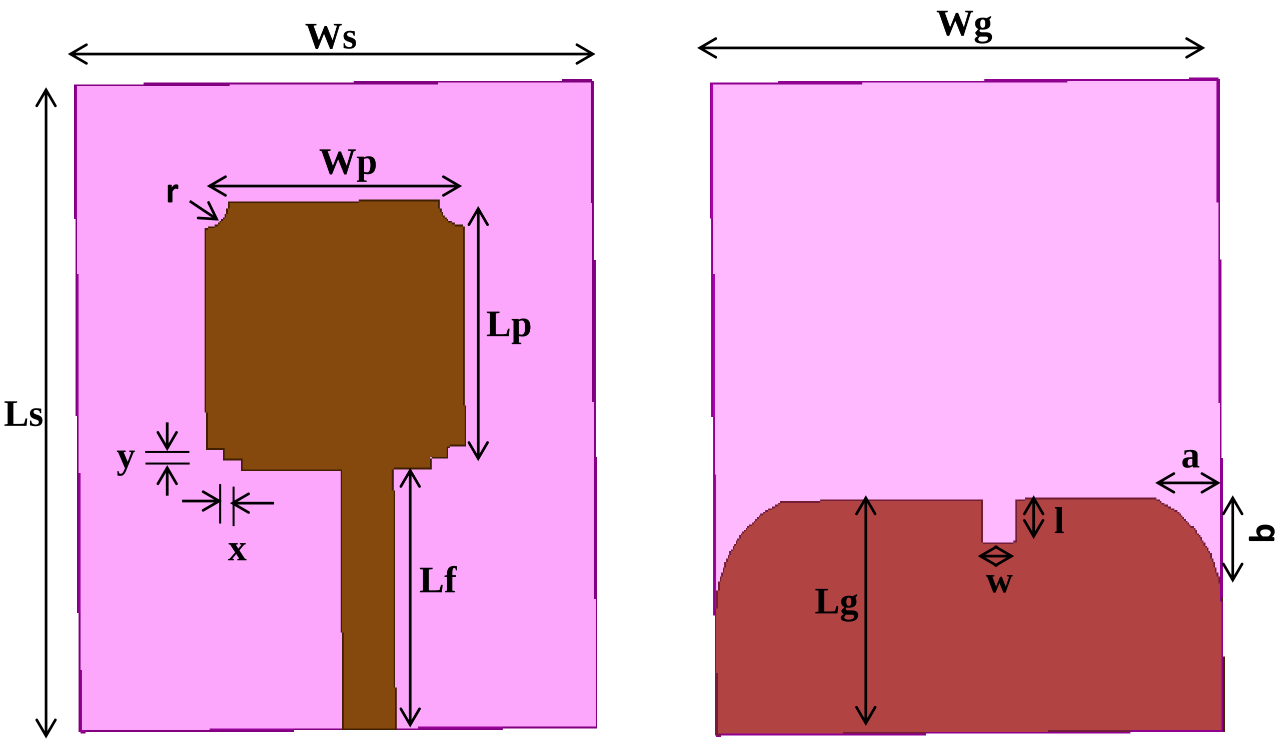


Figure 3.36 Parametric analysis on shift in position of slot in ground plane

In the end, all modifications are done and optimised values are applied for these modifications. After applying the parametric analysis on the ground plane the partial ground is modified to a new shape and the UWB antenna obtained after is shown in Fig 3.37.



a) Patch view b) Ground Plane view

Figure 3.37 Proposed antenna after second stage

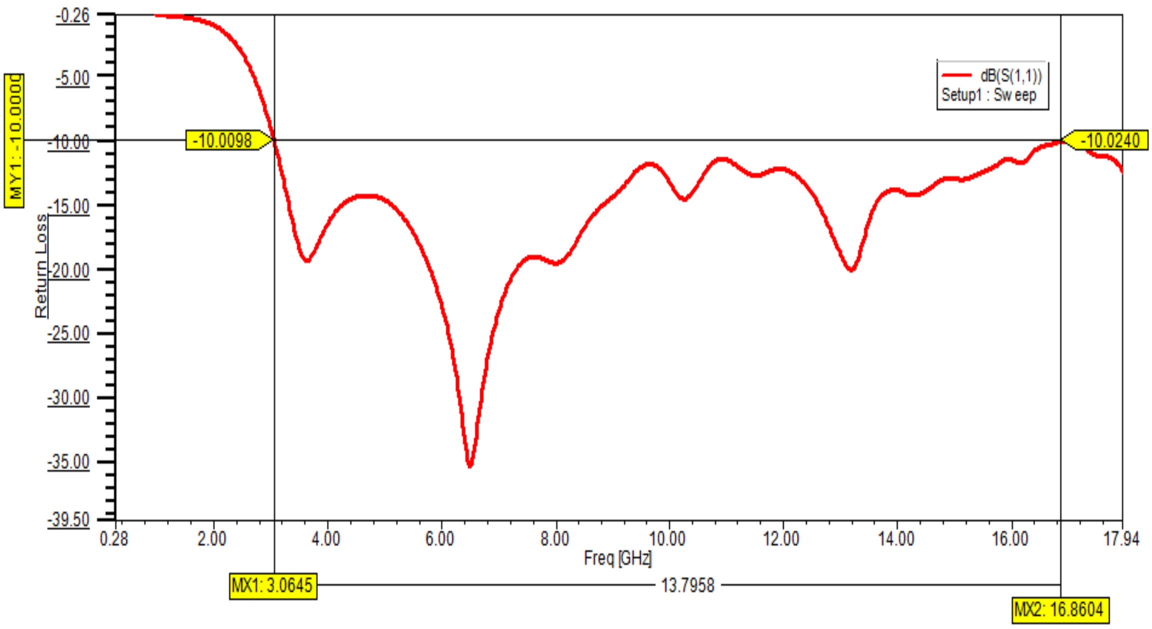


Figure 3.38 Return Loss of proposed antenna after second stage

The Fig. 3.38 shows return loss less than -10 dB over the operating band of 3.1 GHz to 16.8 GHz and peak gain of UWB antenna shown in Fig.3.39 has a value of 3.5

dB at resonating frequency 4.25 GHz and goes on increasing beyond this value and reaches to a maximum value of 12 dB.

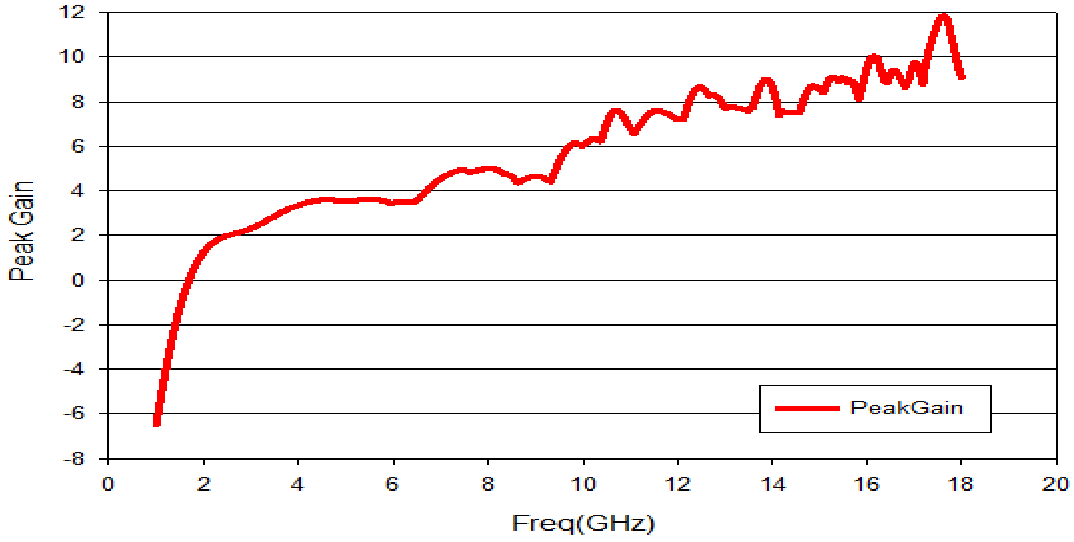


Figure 3.39 Peak Gain of proposed antenna after second stage

Fig. 3.40 shows that the radiation efficiency at the UWB region is 97% and for the rest operating band it is above 80%.

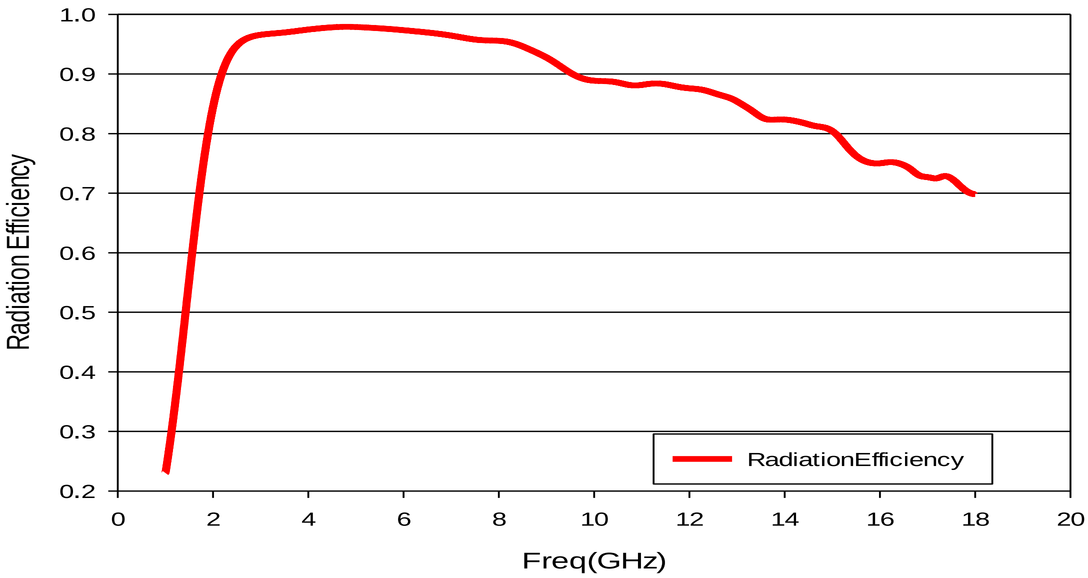


Figure 3.40 Radiation Efficiency of proposed antenna after second stage

The 3-D polar radiation pattern and 2-D radiation pattern for φ=0° and φ=90° of the antenna after stage two are shown in Fig 3.41.

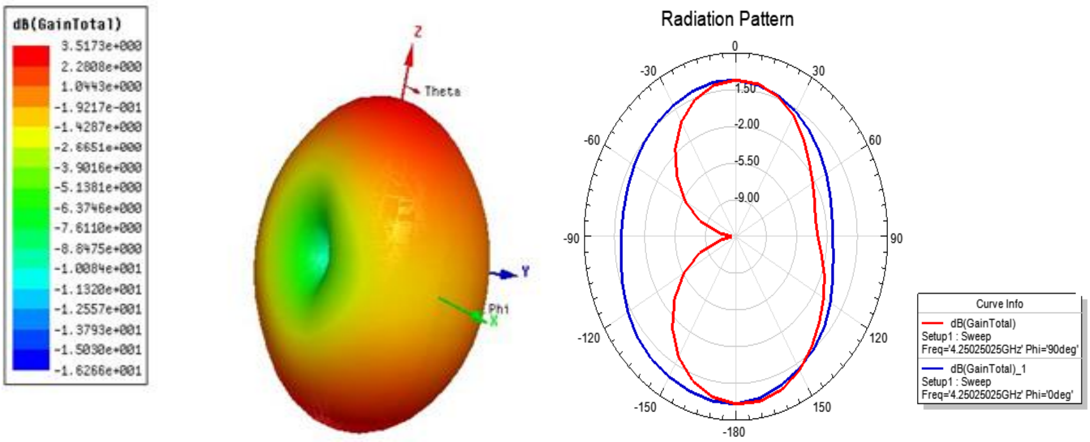


Figure 3.41 3-D polar radiation pattern and 2-D radiation pattern

3.8.4 Controlling the notch using slot length

Due to large operating bandwidth that is from 3.1 to 16.8 GHz of the basic UWB antenna, it is prone to interference from the existing narrowband communication systems like IEEE802.11a (5.15-5.825 GHz) WLAN system and IEEE802.16 (3.3-3.8 GHz) WiMAX system. So UWB antenna with integrated band rejection capability is required. To achieve this rejection capability different shape slots in the feed line and the radiating patch are made. Two slots are proposed in the basic monopole antenna, first one is U-slot made in the feed line, whereas the second circular SRR with gap is etched out in the patch. For the U-slot shown in Fig. 3.42, the parametric analysis is done on its length and the gap between its legs. Whereas, for the circular slot the parametric analysis is performed on the radius of slot, the position of slot and the gap width.

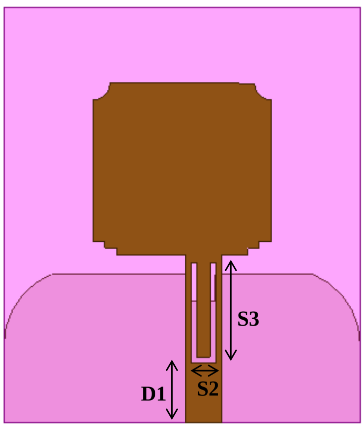


Figure 3.42 Structural view of antenna with U-slot

In Fig. 3.43 results of return loss for parametric analysis on U-slot length, ‘S3’ is shown. The parameter S3 is varied from 1 mm to 9 mm with a step size of 0.5 mm. It can be seen that with the increase in the length parameter ‘S3’ of U-slot, the notched band has shifted from higher frequency to lower frequency. Studying all the results of parametric analysis, the value S3=8.5 mm is selected as it has notched the 4.8 GHz to 5.6 GHz band, which includes the existing WLAN narrow band communication system.

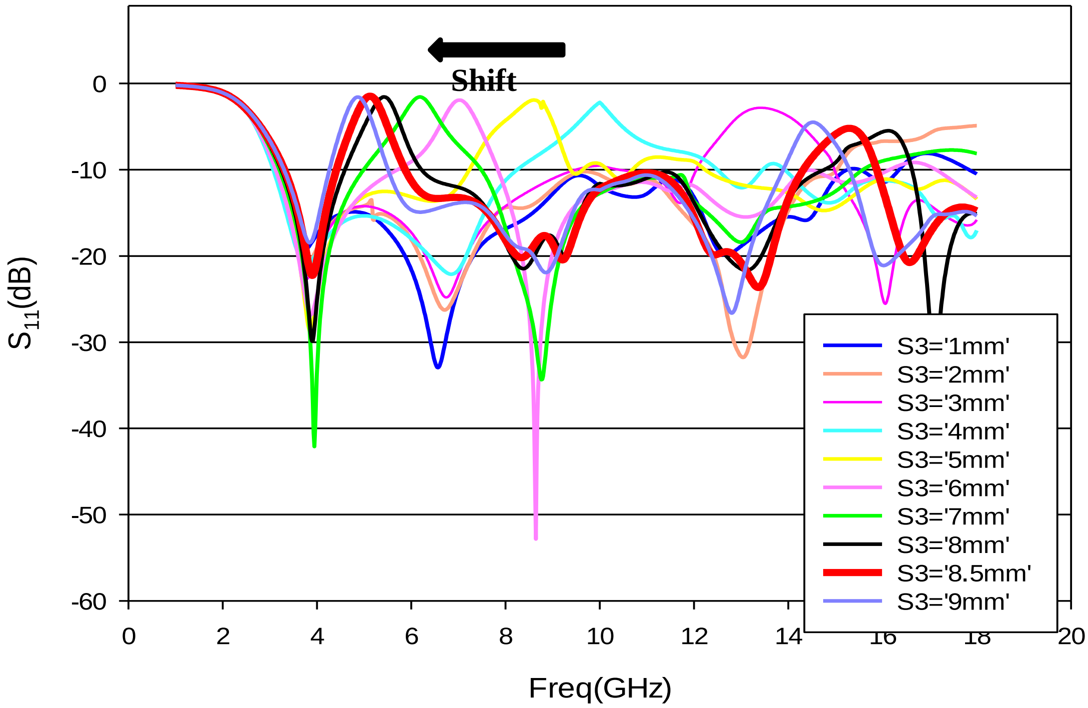


Figure 3.43 Parametric analysis on U-Slot length

In Fig. 3.44 the parametric analysis on the gap between the legs of U-slot, ‘S2’ is shown. The parameter S2 is varied from 1 mm to 2.3 mm with a step size of 0.1 mm. It can be seen that with the increase in the gap parameter ‘S2’ of U-slot, the notched band has shown control over its bandwidth. Studying the results of parametric analysis, the value S2=2.1mm is selected as it has notched the 4.4 GHz to 5.8 GHz band, which covers the existing band IEEE802.11a(5.15-5.825 GHz) for the WLAN system.

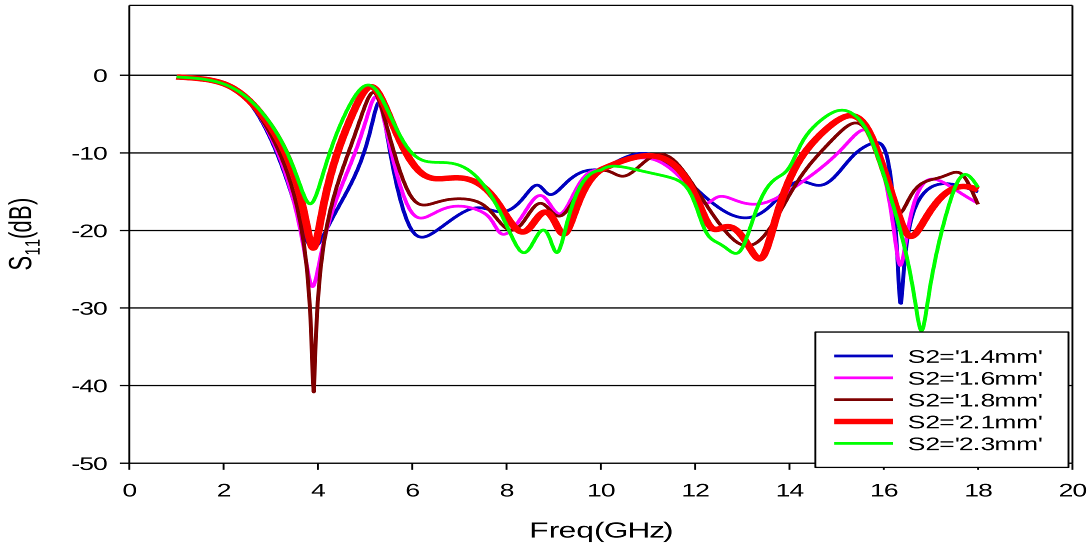


Figure 3.44 Parametric analysis on U-Slot gap

A circular SRR with a gap width is etched out of the radiating patch as shown in Fig 3.45, to remove the interference due to existing narrowband communication systems IEEE802.16(3.3-3.8 GHz) WiMAX.

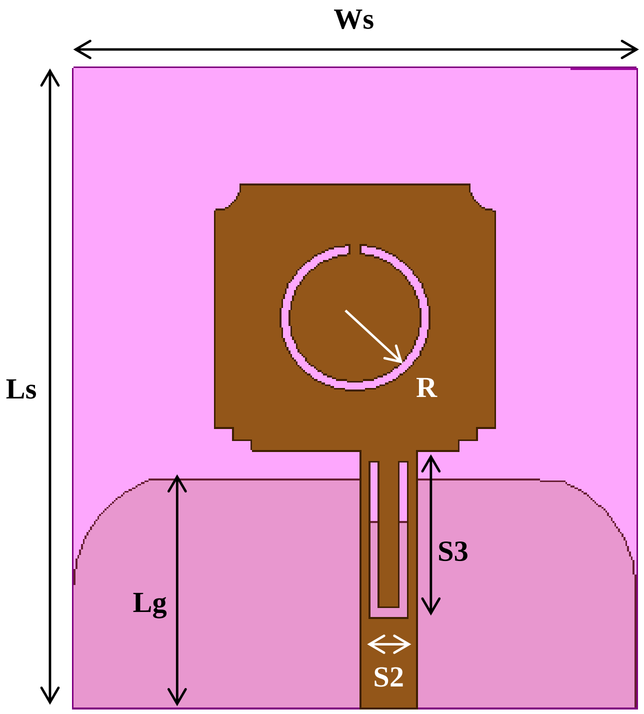


Figure 3.45 Structural view of Antenna with circular SRR with gap

The parametric analysis performed on the radius of this circular SRR with gap is shown in Fig. 3.46. The radius of this circular slot is varied from 4 mm to 5 mm with a step size of 0.05 mm. The R= 4.65 mm value is selected as it has given improved return loss characteristics.

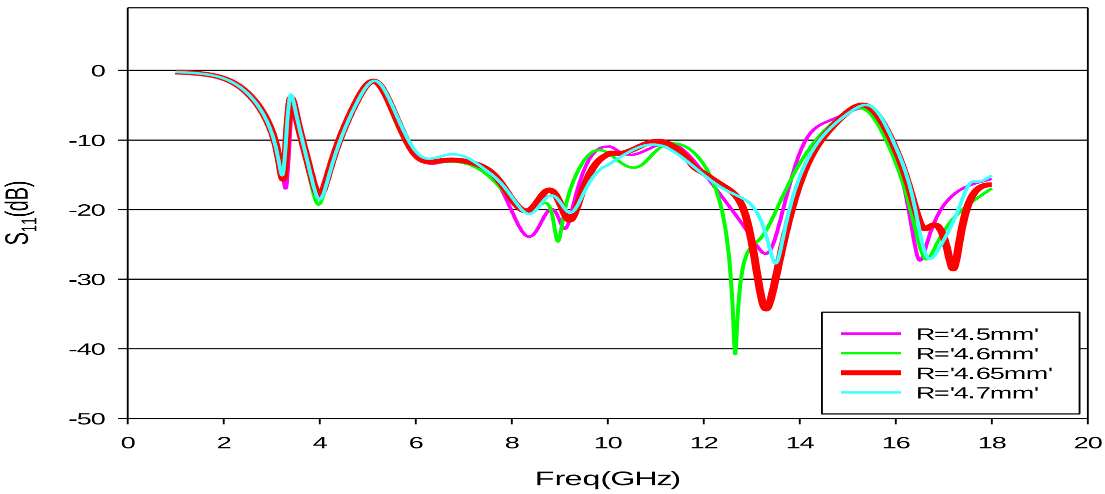


Figure 3.46 Parametric analysis on radius of circular SRR with gap in patch

Then in the next part, the parametric analysis is performed on the position of circular SRR with gap, which is shown in Fig. 3.47. The position of this circular SRR is shifted from -2.5 mm to 2.5 mm with a step size of 0.5 mm with respect to the centre position of patch. The c= 0 mm value is selected as it has no visible effect in controlling the bandwidth of either notch or on the operating frequency band.

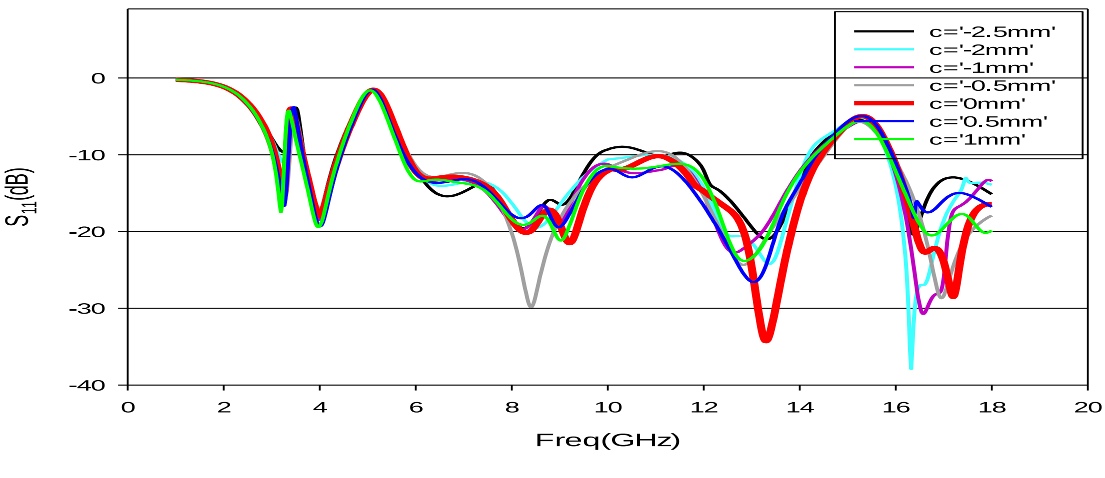


Figure 3.47 Parametric analysis on position of circular SRR with gap in patch

The parametric analysis performed on the width of the circular SRR gap is shown in Fig.3.48. The gap of this circular SRR is varied from 0.1 mm to 1 mm with a step size of 0.1 mm. The g= 0.5 mm value is selected as it has helped in improving the return loss.

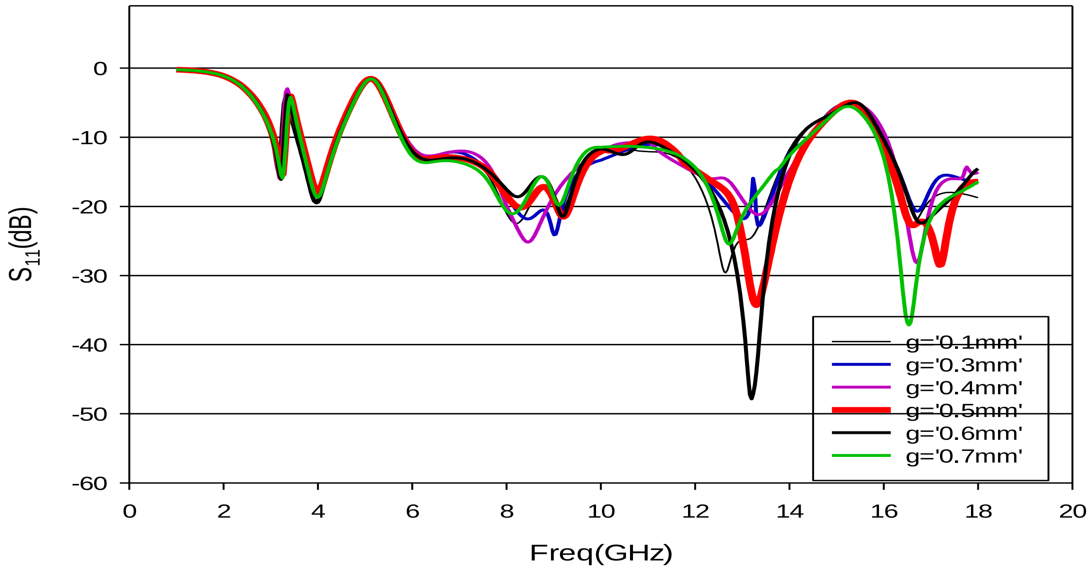
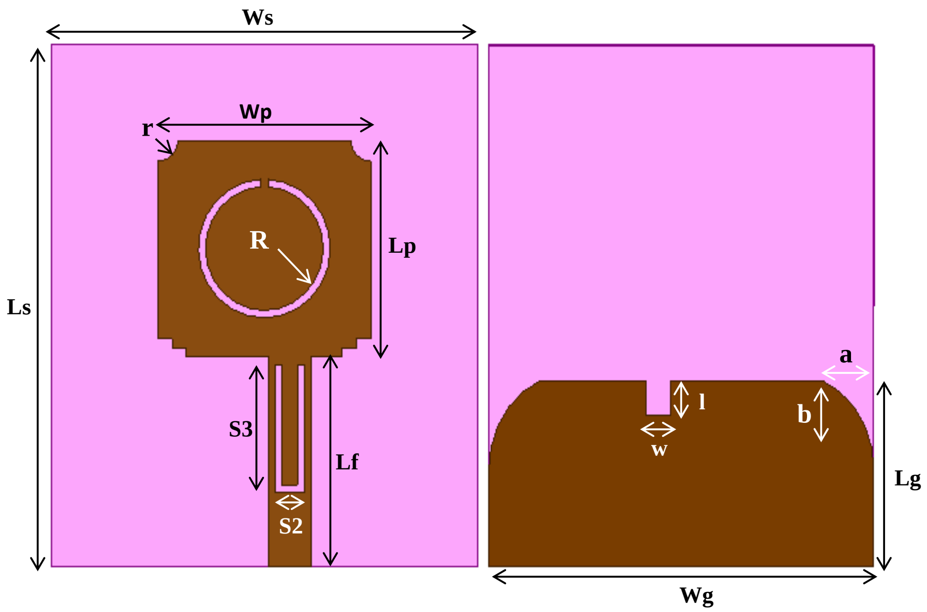


Figure 3.48 Parametric analysis on gap of circular SRR with gap in patch

3.8.5 Geometrical view of the proposed antenna

The Fig.3.49 shows the geometrical view of the proposed antenna and table 3.2 shows the optimised values of structural parameters. The overall area of the substrate is



a) Patch view **b) Ground Plane view**

Figure 3.49 Proposed antenna

Table 3.2 Dimensions of the Proposed antenna

Parameters	Length (mm)	Parameters	Length (mm)	Parameters	Length(mm)
Ws	30.0	Lf	14.1	y	0.6
Ls	35.0	Wf	3.05	x	1.0
h	1.6	S2	2.1	R	4.65
Wg	30.0	D1	5.0	s	1.8
Lg	12.5	T1	0.5	sh	1.8
Wp	15.0	S3	8.5	l	2.3
Lp	14.5	r	1.4	w	2.0
c	0.0	g	0.5		

3.9 Fabrication of Proposed Antenna

After the completion of designing the proposed antenna the next step is to fabricate the optimally designed antenna. There are various steps which are needed to be performed sequentially in order to get the desired results. The First step starts with generating the ***.dxf*** (drawing exchange format) file. The designed antenna can be fabricated using the Printed Circuit Board prototype designing machine. For performing the fabrication of designed antenna the PCB prototype designing machine requires the gerber file format, which is an open ASCII vector format for 2D binary image used as standard electronics industry file format. The PCB prototype software converts the ***.dxf*** file into the gerber file. The different steps involved in the fabrication process are shown in Fig.3.50.

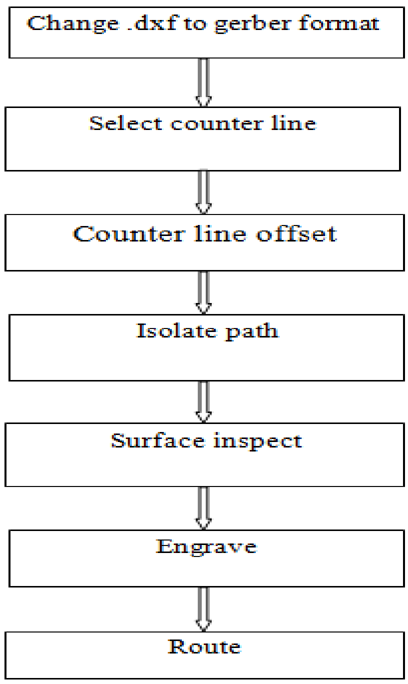
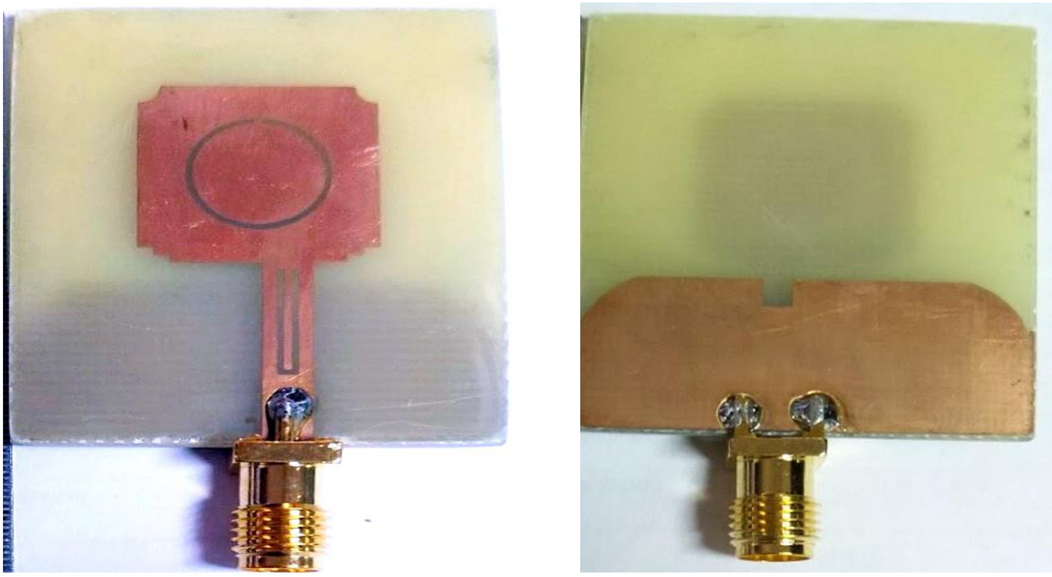


Figure 3.50 Steps involved in the PCB prototype software

After the fabrication is done, the next step is to connect SMA (Sub Miniature version A) connector using the solder with the feed line to give the excitation needed by the antenna. Using this SMA connector the antenna is connected to VNA (Vector Network Analyzer) though probe wire to measure the performance parameters of the fabricated antenna. The dimensional view of the fabricated antenna is shown in Fig. 3.51 and Fig.3.52.



(a) Patch view **(b) Ground view**

Figure 3.51 Fabricated view of proposed antenna

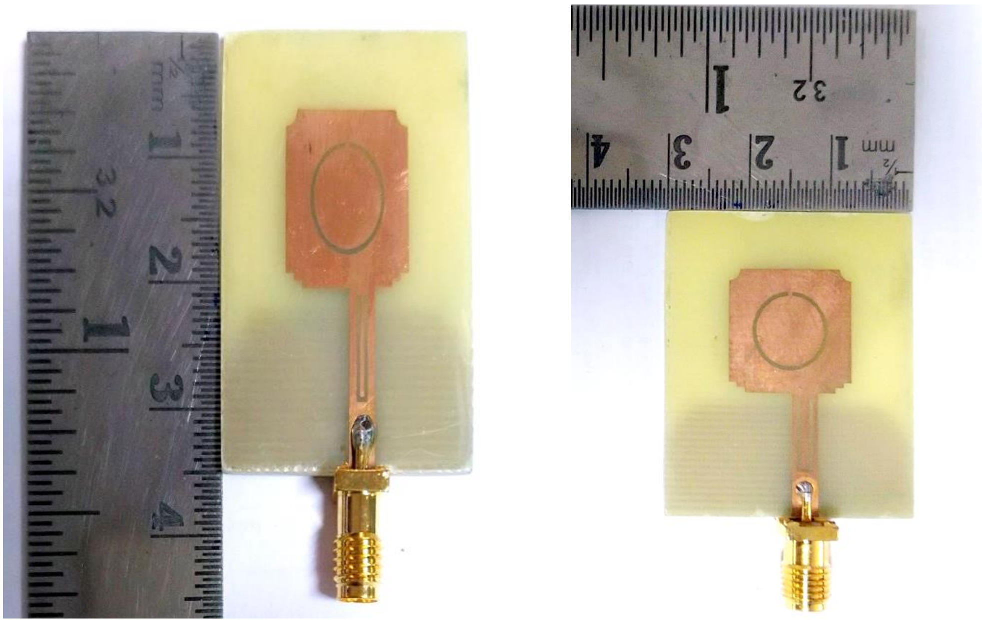


Figure 3.52 Dimensional view of proposed antenna

3.10 Method of Testing

The measurement of return loss and the VSWR of the fabricated proposed antenna is done on VNA. The proposed antenna is tested on a vector network analyzer (VNA) in the frequency range from 1 to 18 GHz.

The setup of VNA is shown in Fig. 3.53 in which the fabricated proposed antenna is connected with VNA using the connecting probes.

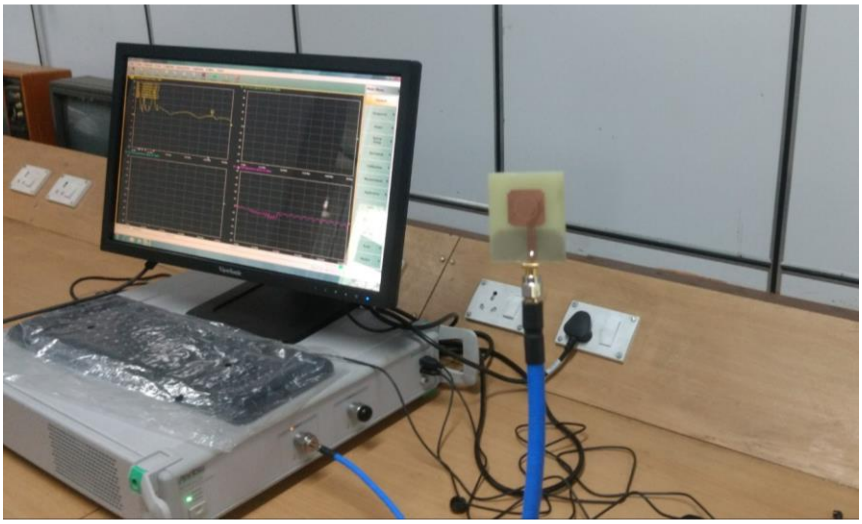


Figure 3.53 Testing setup for VNA

Fig. 3.54 shows the anechoic chamber used for the measurement of gain and radiation pattern. The horn antenna is used as a reference antenna to measure the parameters.

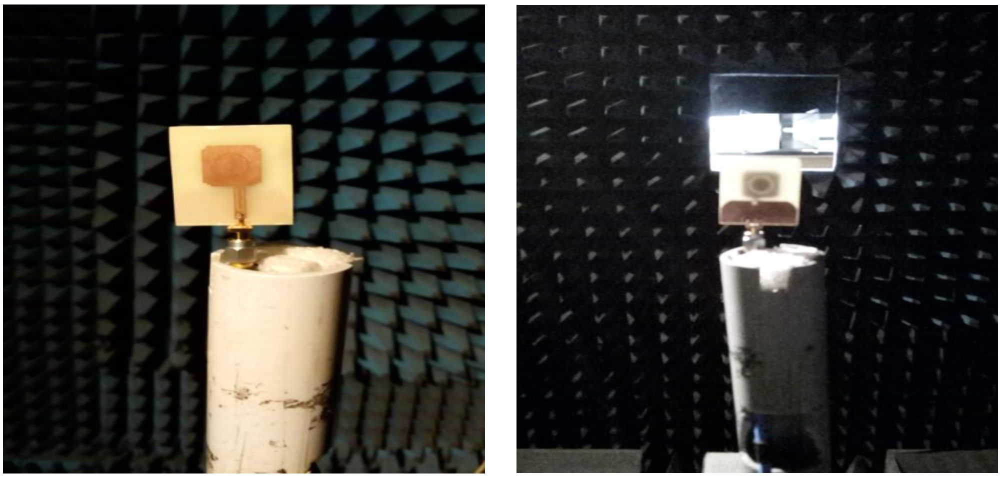


Figure 3.54 Testing setup in anechoic chamber

The next chapter discusses the measurement of various parameters of the proposed antenna and consists of comparison between the simulated and measured results.

Results and Discussion

Previous chapters have discussed the method of the antenna design using the Transmission Line Model, simulation of the designed antenna using HFSS software, fabrication of the simulated antenna using the PCB prototype designing machine and then the testing of the proposed antenna is done on VNA.

Chapter 4 includes the simulated and the measured results of fabricated antenna for parameters like the return loss, VSWR, peak gain, radiation pattern, antenna efficiency.in the last part of this chapter a comparison is made between the parameters obtained for the simulated and the fabricated antenna's.

4.1 Proposed Antenna Simulated Results

At the setup frequency of 4.25 GHz, the proposed antenna is simulated in the frequency range of 1-20GHz. Fig. 4.1 shows the variation of S_{11} parameter having peaks at 3.2GHz, 4 GHz, 4.25GHz, 8.2GHz, 9.2GHz and 13.3GHz with -15.6dB, -17.86dB, -13.45dB, -20.17dB, -21.34dB and -32.28dB of S_{11} values respectively. The graph shows the frequency bands present 3.1-14.45GHz with the bandwidth of 11.35GHz.The frequency bands from 3.31-3.6GHz and 4.4-5.8GHz are being notched out so that the interference due to the existing narrowband communication systems like IEEE802.16 (3.3–3.8 GHz) WiMAX system and IEEE802.11a (5.15–5.825 GHz) WLAN system can be eliminated.

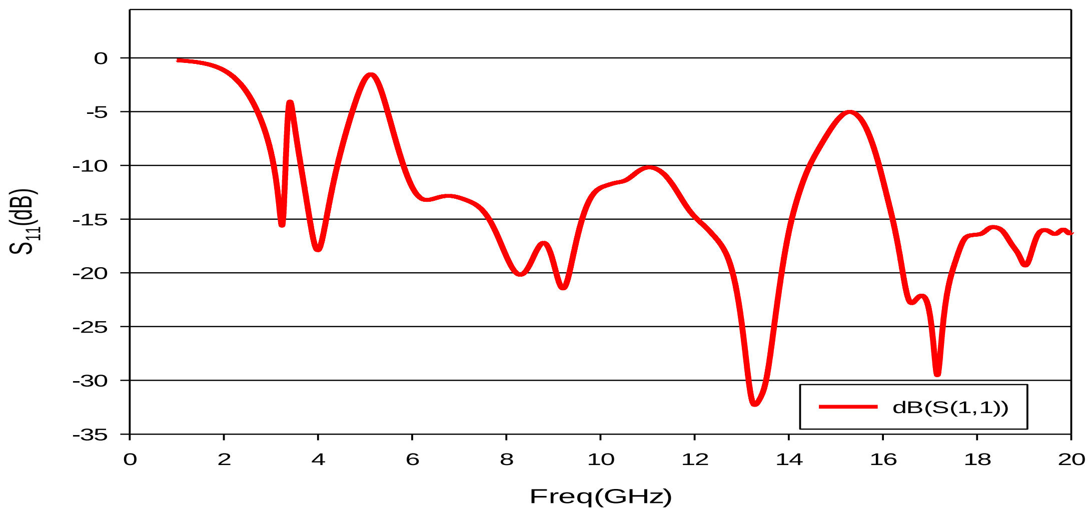


Figure 4.1 Simulated S_{11} of proposed antenna

Fig. 4.2 shows that the value of VSWR in the operating frequency band has values between the ranges of 1 and 2, also at the notched frequency bands, the VSWR values are above 2. The value shows that the impedance of microstrip patch antenna and that of transmission line feeding is well matched. Due to this proper impedance matching more power is being delivered to the radiating antenna and less power is reflected back.

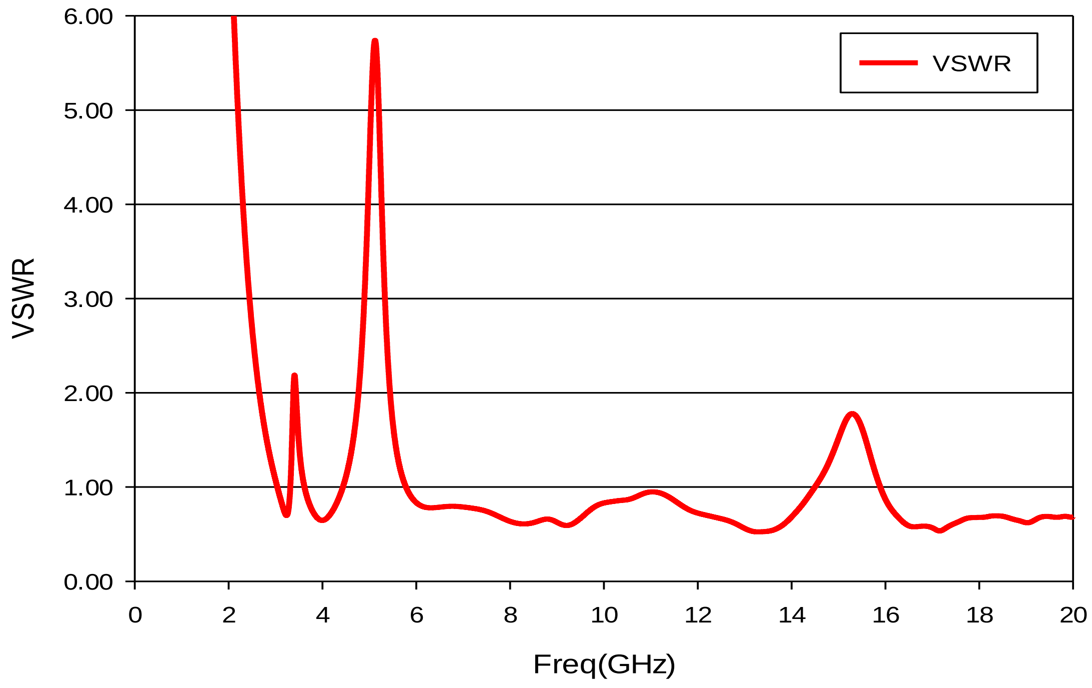


Figure 4.2 Simulated VSWR of proposed antenna

Simulated peak gain of proposed antenna in Fig. 4.3 shows that the peak gain is positive and above 2dB after 2 GHz frequency and shows an increase in its value with the frequency. At the frequency points of 3.2GHz, 4 GHz, 4.25GHz, 8.2GHz, 9.2GHz and 13.3GHz with return loss of -15.6dB, -17.86dB, -13.45dB, -20.17dB, -21.34dB and -32.28dB respectively the peaks has the values of peak gains 2.17dB, 3.03dB, 3.15dB, 4.42dB, 4.5dB and 9.24dB respectively. Also at the notched frequency bands the value of peak gain is negative, which confines its notching characteristics.

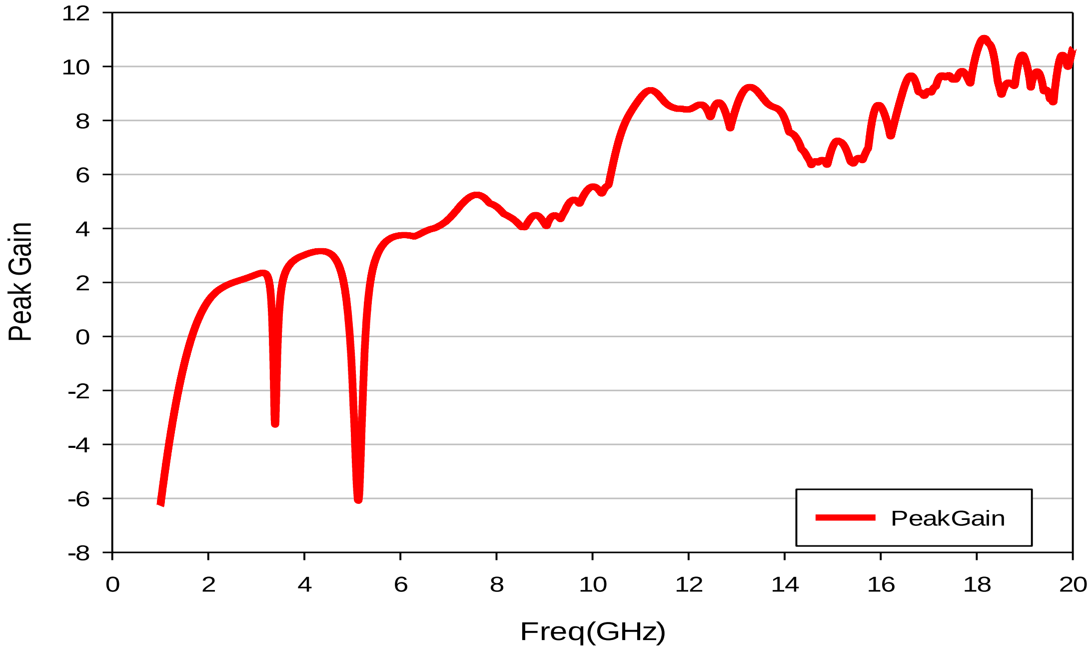


Figure 4.3 Simulated peak gain of proposed antenna

The simulated efficiency of the proposed antenna is shown by the graph in Fig.4.4, it shows that the proposed antenna efficiency is above 90% from 3.1-10 GHz and the value lies in the range of 80-90% for the operating frequency band of 10-14.5 GHz. Also at the notched frequency bands the radiation efficiency has shown drop in its values below 20%.

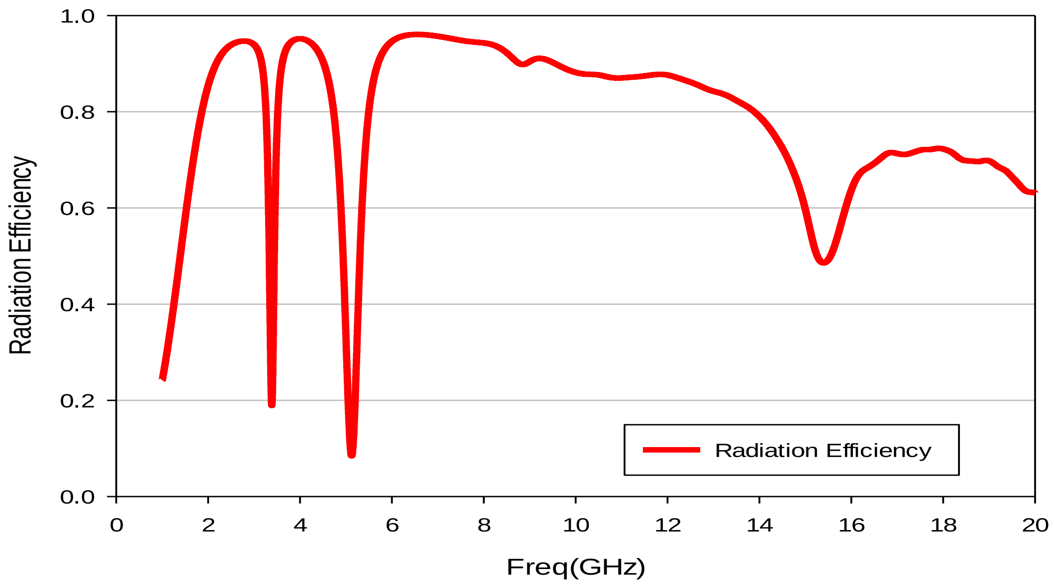


Figure 4.4 Simulated radiation efficiency of proposed antenna

4.2 Measured Results of Proposed Antenna

Fig. 4.5 shows the measured value of S_{11} parameter of the proposed antenna shown by VNA. The measured graph shows that the antenna is resonating over the frequency band of 3.18-14.9 GHz with the bandwidth of 11.7 GHz. Main peaks are at 3.3GHz, 4.1GHz, 8.4GHz, 12.8GHz and 13.9GHz with return loss of -20.2 dB, -14.5 dB, -18 dB,-20 dB and -19 dB respectively. At the notched frequency band the peak occurs at 3.63 GHz and 5.1 GHz with return loss -2.5 GHz and -2.4 GHz.

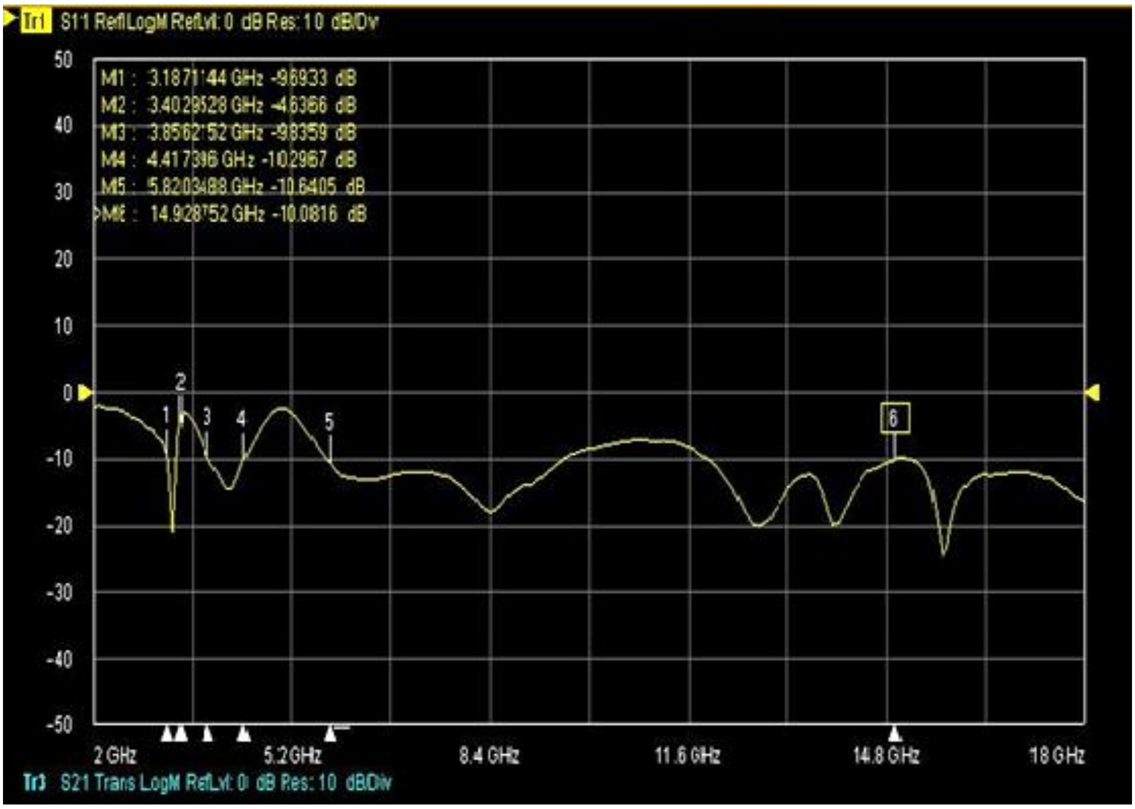


Figure 4.5 Measured S_{11} of proposed antenna

The Fig.4.6 shows that the measured value of VSWR on VNA has values between the range of 1 and 2 in complete operating frequency range where return loss is below -10 dB, whereas the notched frequency band has VSWR greater than 5.

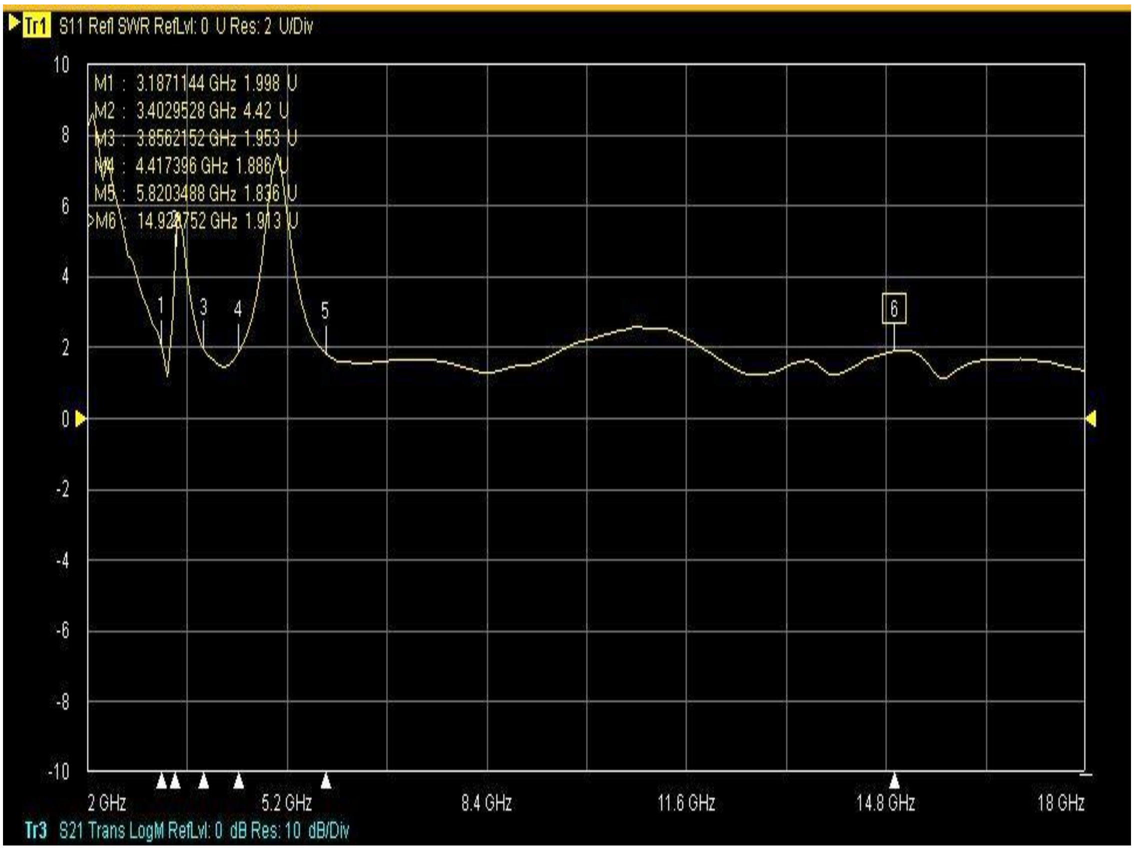


Figure 4.6 Measured VSWR of proposed antenna

4.3 Comparison of Simulated and Measured Result of Antenna

Over the frequency range of 1-20 GHz, the comparison of the both simulated and measured results is being accomplished using the .csv (comma separated values) file taken from both the simulation software HFSS results and the VNA respectively. The Fig.4.7 shows a good resemblance between the simulated and the measured S_{11} (return loss) values. Also, the comparison between the simulated and the measured value of VSWR is shown in Fig.4.8 shows a close resemblance between the two results. A slight discrepancy can be seen in both the graphs between the simulated and the measured results, this discrepancy is seen due to some losses occurring during the fabrication (known as fabrication losses) and at the time of testing the antenna the radiation losses.

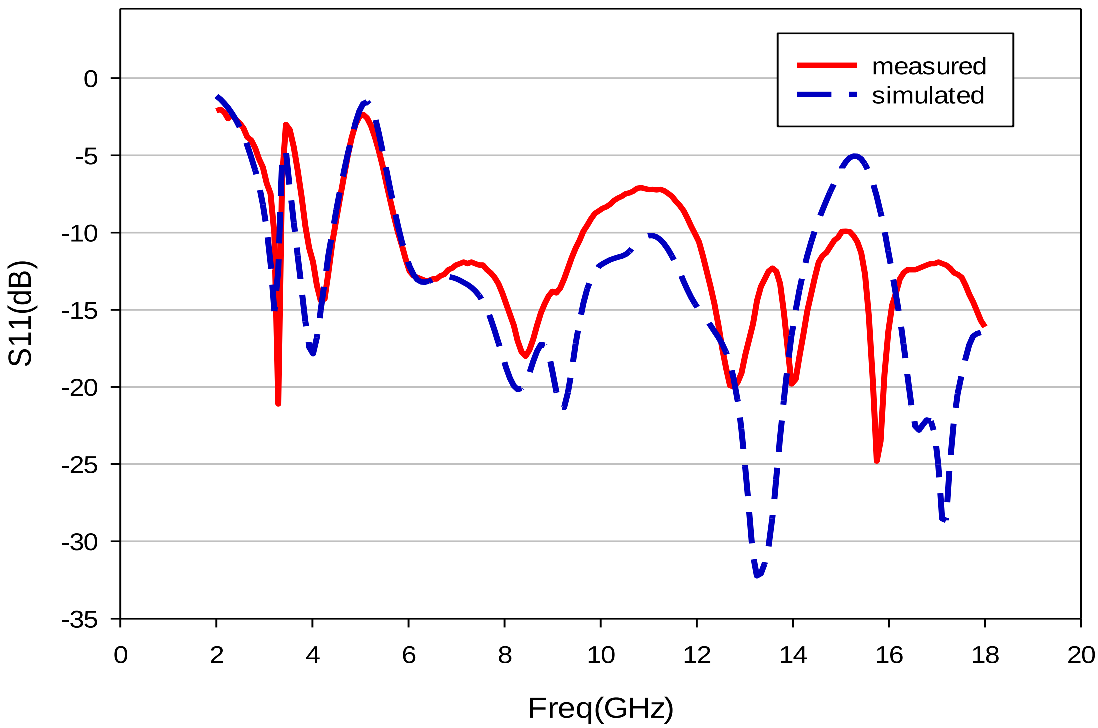


Figure 4.7 Comparison of simulated and measured S_{11} of proposed antenna

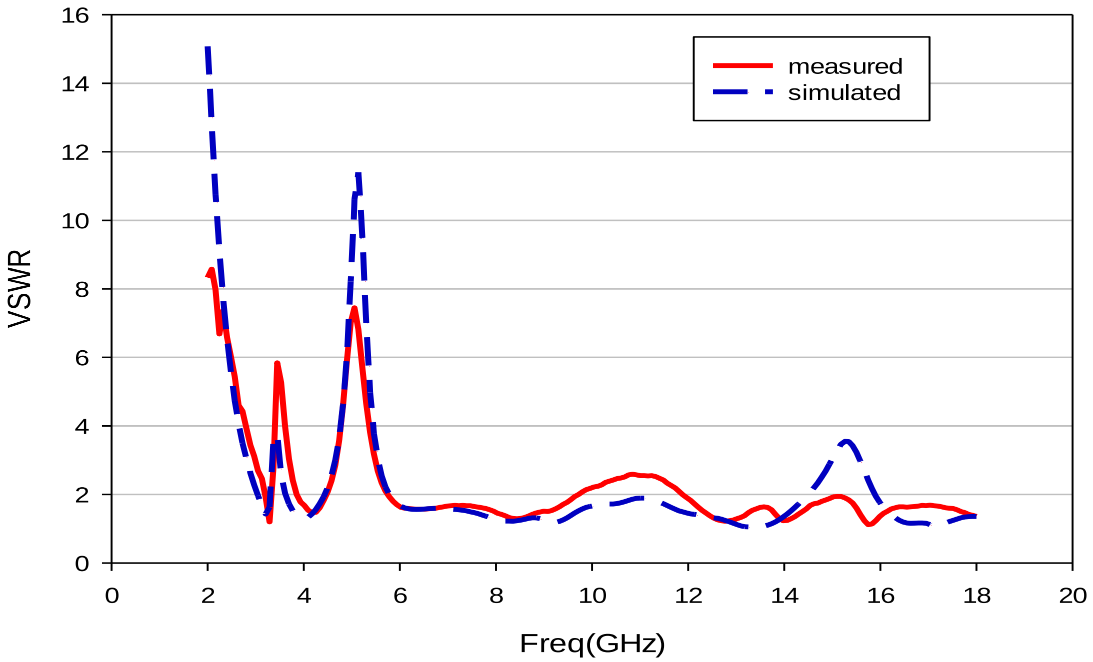
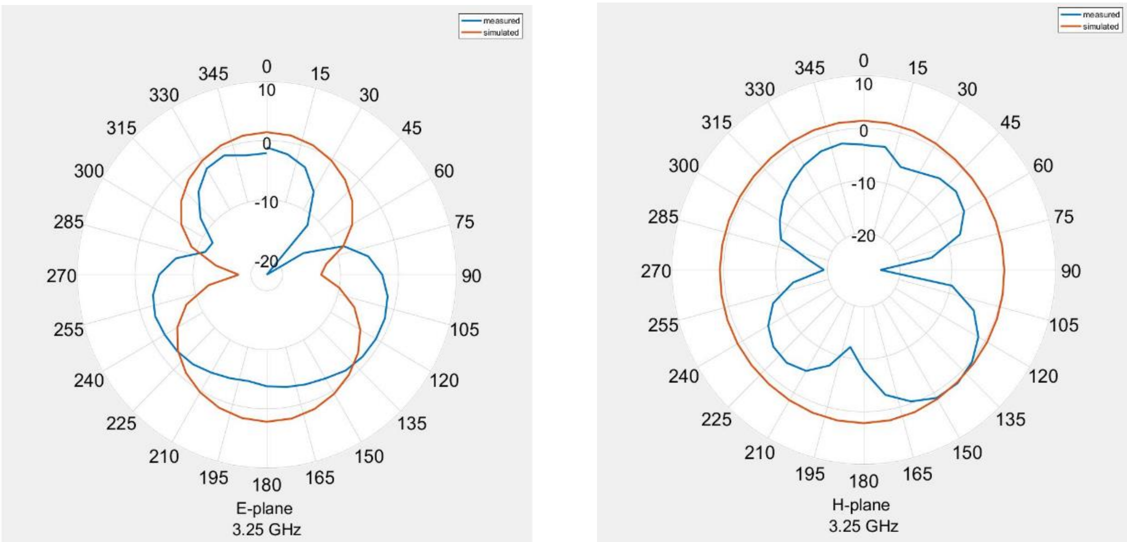
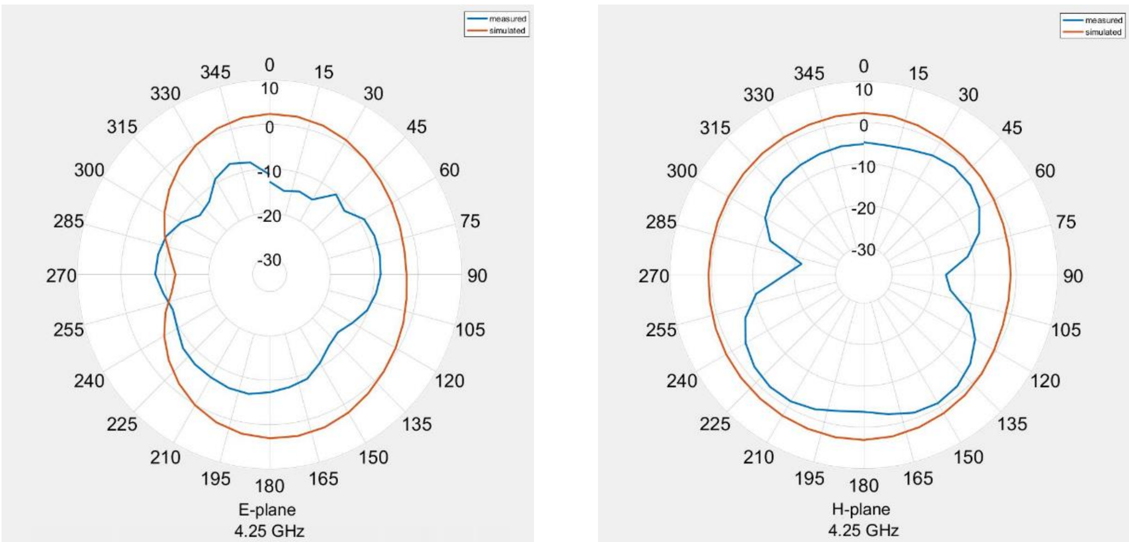


Figure 4.8 Comparison of simulated and measured VSWR of proposed antenna

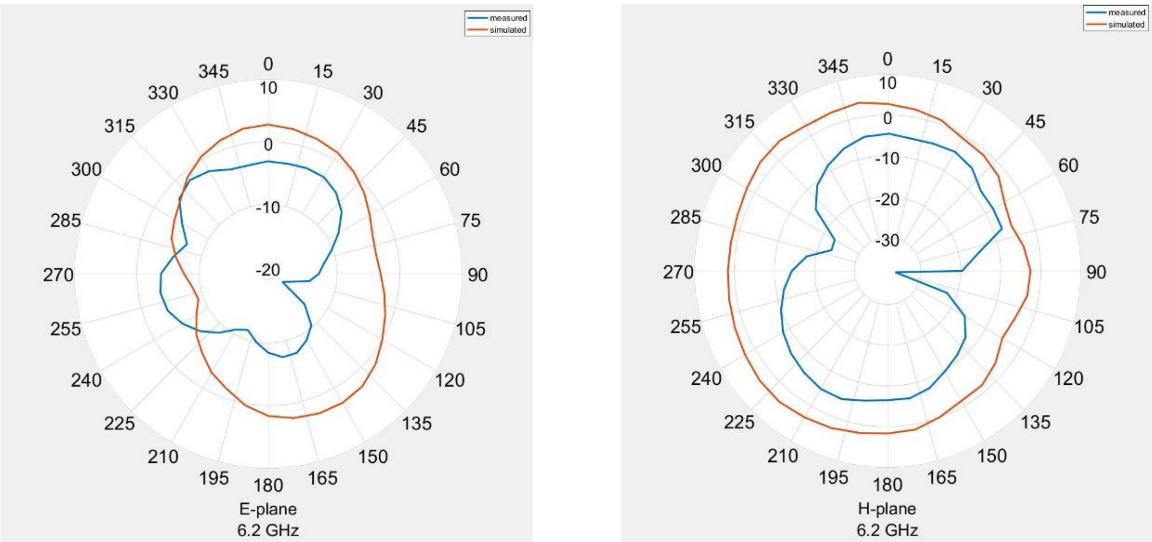
Fig.4.9 shows the comparison of radiation pattern for both simulated and measured results (both E plane and H plane) of an antenna at different frequency points



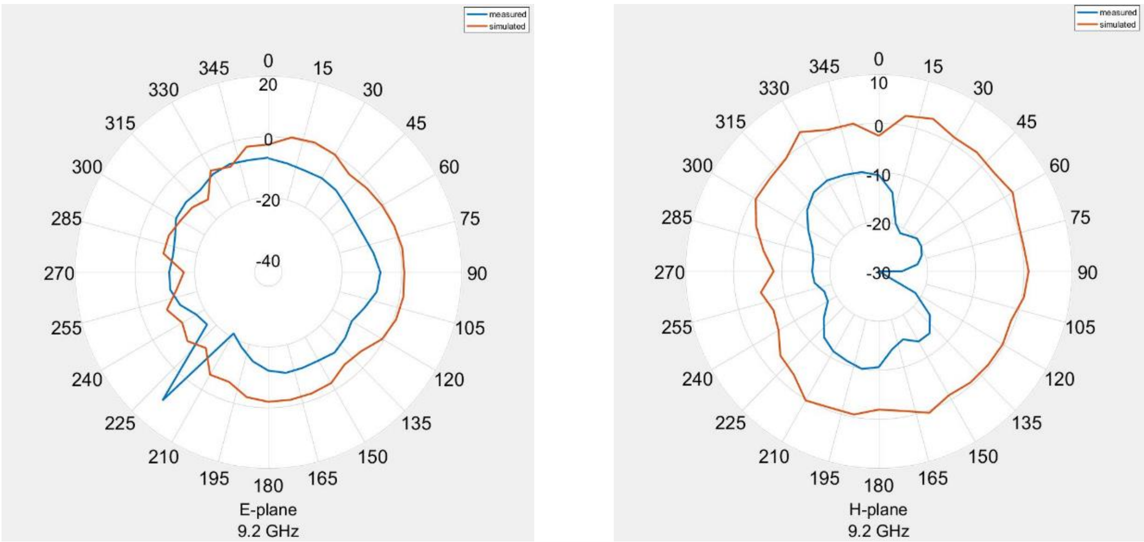
a) E & H Plane at 3.25 GHz



b) E & H Plane at 4.25 GHz



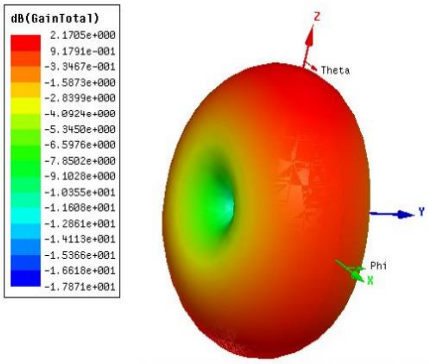
c) E & H Plane at 6.2 GHz



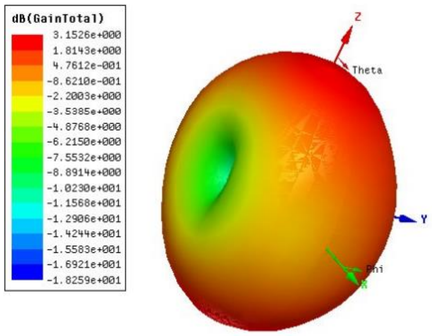
d) E & H Plane at 9.2 GHz

Figure 4.9 Radiation pattern of proposed antenna at different frequencies

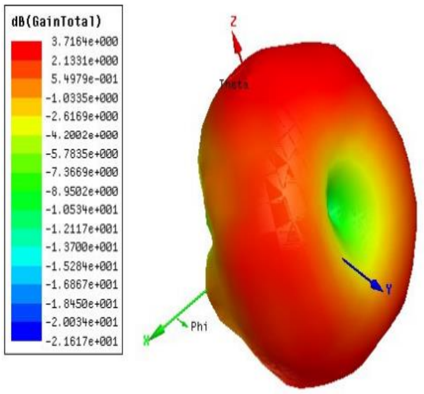
Fig.4.10 shows the 3D polar plot of the proposed antenna at different frequency points



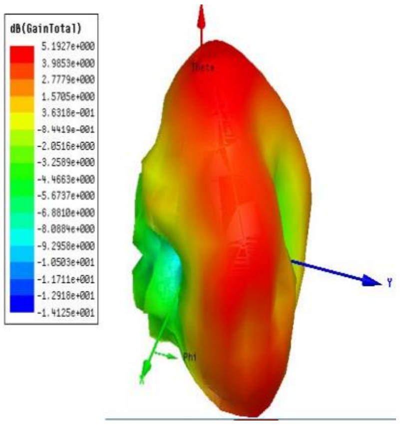
a) 3.25GHz



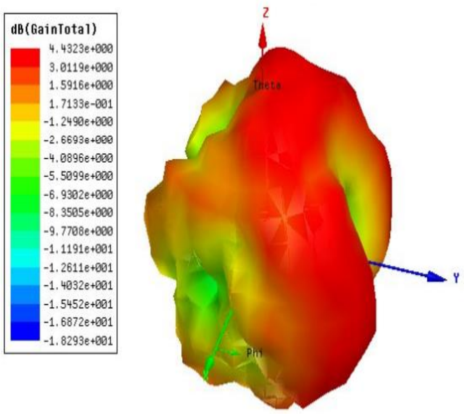
b) 4.25GHz



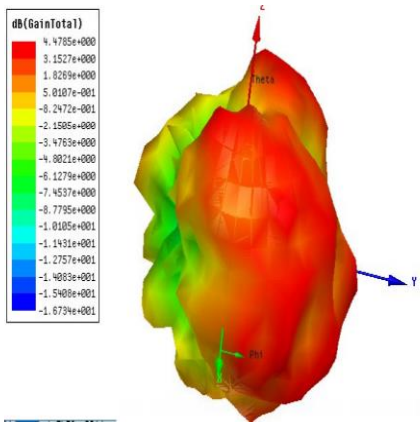
c) 6.2 GHz



d) 7.5 GHz



e) 8.25GHz



f) 9.2 GHz

Figure 4.10 3D polar plots of proposed antenna at different frequencies

Summary and Conclusions

The antenna is an extremely indispensable part of the systems in wireless systems that use a transmitter and a receiver antenna as the transducer converting an electrical signal into an EM signal or vice-versa. Depending on application different types of antenna are used, the MSA is also one of them which are mostly used these days because it has easy fabrication and low cost for wireless communication applications. To further improve the performance of the MSA, various techniques are used like by using different feeding types perfect impedance matching is achieved, by introducing slots with different shapes the effective path for the current is increased and DGS method to performance enhancement.

Chapter 5 summarizes the work done during the process of designing and fabrication of proposed UWB microstrip antenna with controllable notched characteristic for wireless applications over frequency range from 3.1-14.45GHz. The TLM method is used for obtaining the various dimensions of conventional patch antenna having rectangular shape operating over an ultra-wide band range of wireless applications. The ground is modified to enhance the performance characteristic of patch antenna; also to reject the interference present due to certain frequency bands two slots are cut in patch.

In chapter 1, brief introduction about the MSA which operates over UWB frequency region of wireless applications is given. Introduction of monopole antenna, the defected ground structure, notching and their role in further improving the performance of MSA is also described. It also includes the objectives which are decided while the start of this research and also specify the process to be followed to achieve these desired objectives.

Chapter 2 has a review of literature of previous work which is done in field of MSA antenna, DGS and notching. It has an explanation of the various researches done by different scientists and the obtained results, which helped in designing the proposed antenna.

The 3rd chapter has an elaborated explanation for the materials and methods which are used while designing and fabrication of the proposed MSA antenna. In the first part, the introduction of the MSA, various feeding techniques, different methods of analysis or models that can be used in designing the patch antenna. It also explains how DGS can further enhance performance of an antenna and different shape slots to obtain the notch characteristics. In second part of this section details about the simulation software i.e. HFSS used for simulation are described. In this section of the chapter various steps which are executed in the designing of antenna using the simulation software are explained in detail. The design steps implemented on the structure of antenna and their effects are shown. While designing proposed antenna, the value of the optimized parameters was obtained with the help of parametric study are also mentioned. In the last part the steps which are involved while the fabrication and measurement of antenna proposed are also mentioned.

Chapter four has the results of the proposed research work, different antenna parameters like return loss, VSWR, gain and radiation pattern at different operating frequencies are explained. In next part a comparison is made between the simulated results and results obtained for fabricated antenna. The designed antenna with dimension of 35mm×30mm shows simulated results having return loss below -10dB over the frequency range 3.1 GHz to 14.45GHz with bandwidth of 11.35GHz. The value of VSWR lies below 2 over resonating band indicates that the antennas patch and feed line have proper impedance matching. The measured and simulated results are matched, showing some variations that may be present due to radiation and fabrication loss.

The proposed antenna works on an Ultra-wideband frequency range of wireless communication while rejecting the 3.31-3.6GHz and 4.4-5.8GHz so that the interference due to the existing narrowband communication systems like IEEE802.16 (3.3–3.8 GHz) WiMAX system and IEEE802.11a (5.15–5.825 GHz) WLAN system can be eliminated. The proposed work has shown that performance of patch antenna in terms of operating bandwidth, gain, etc. can be improved by using the defected or modified ground structure and the variation in slots dimension can be used to control the notched frequency band by increasing the effective current flow path. Also by optimizing the feed line width, feed length and its location have shown improvement in the results.

Future scope

Future scope of improvement that can be exploited in the related area of research is:

- As the antenna proposed has FR-4 material as a substrate with $\varepsilon_r = 4.4$ and loss tangent=0.02. The parameters like gain of antenna can further be improved if substrate material of low ε_r is used.
- Distinct techniques like etching slots with different shapes and sizes can be made to reduce the size of antenna can further be reduced.
- With certain modifications in feeding techniques improvement in the performance of the patch antenna is seen. Like by employing the coaxial probe feeding method, better matching of impedance and by using proximity-coupled feeding the wider bandwidth can be achieved.
- The PCB designing machine has a precision of 0.5mm, so by using more précised machine, width of slot can be further reduced making space for more slots thereby increasing the effective path of the current and lower resonating frequency values can be achieved.

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VITA

The author of this manuscript, Sunil Sharma was born on 12th March, 1988 at Dehradun, Uttarakhand. He passed his High School and Intermediate from Shri Guru Ram Rai Public School, Patel Nagar, Uttarakhand from C.B.S.E board, during the year 2004 and 2006, respectively. He earned his B.Tech. in Electronics & Communication Engineering from Uttaranchal Institute of Technology, Dehradun, Uttarakhand during the year 2011. Thereafter, he joined G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, in 2017 for the degree of Master of Technology with major in Electronics &Communication Engineering.

Permanent Address:

Sunil Sharma
S/o Inderjeet Sharma
D-9 Patel Nagar
Dehradun, Uttarakhand— 248001
Mobile No. - 9634863315
Email- er.sunilsharma1203@gmail.com

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ABSTRACT

Name	: **Sunil Sharma**	**Id. No.**	: **52460**
Semester and Year of Admission	: First 2017-18	**Degree**	: M.Tech (E&CE)
		Department	: E&CE
Major	: Electronics & Communication Engineering		
Thesis title	: **Controllable Notched Edge Tapered Rectangular patch antenna using U-slot line feed and DGS for UWB Applications**		
Advisor	: **Dr. Paras (Associate Professor, E&CE)**		

Antenna is an extremely indispensible part of wireless communication systems. As the requirements of wireless devices increasing day by day like Bluetooth devices, radio frequency devices and size of such devices decreasing accordingly. To meet the requirement of small size devices, antenna need to be compact and single antenna can be used for several wireless applications, without affecting the antenna parameters. Therefore the concept of ultra-wideband is used. The defected ground structure and slotting is used to enhance the performance of antenna.

Proposed antenna is designed in the substrate size of 35×30 mm^2 with height of 1.6mm. FR-4 epoxy substrate having permittivity of 4.4 and loss tangent of .02 is used. Ground size is reduced to obtain monopole antenna and slots are cut on both patch as well as ground plane to improve the performance of antenna in terms of bandwidth and gain. Proposed antenna is simulated using Ansoft HFSS software, fabricated in PCB designing machine and tested using VNA. Proposed antenna resonates in 3.1-14.45GHz band with notched frequency bands from 3.31-3.6GHz (WiMAX) and 4.4-5.8GHz (WLAN) with the bandwidth of 11.35 GHz having gain above 2.17dB and efficiency 80-90% throughout the entire frequency range. Proposed antenna has applications in UWB frequency range with no interference for WiMAX and WLAN band in wireless communication.

(Paras)
Advisor

(Sunil Sharma)
Author

सारांश

नाम	: सुनील शर्मा	**परिचयांक सं.**	: ५२४६०
सत्र एव प्रवेश वर्ष	: प्रथम ,२०१७-१९	**उपाधि**	: प्रौद्योगिकी में परास्नातक
मुख्य विषय	: इलेक्ट्रॉनिक्स एवं संचार अभियांत्रिकी	**विभाग**	: इलेक्ट्रॉनिक्स एवं संचार अभियांत्रिकी

शोध का शीर्षक : नियंत्रित नॉचड टेपर्ड किनारे आयताकार पैच एंटीना यू- स्लॉट लाइन फीड और डीजीएस का उपयोग करके अल्ट्रा-वाइडबैंड अनुप्रयोगों के लिए

सलाहकार : डॉ पारस (सह – प्राध्यापक, इलेक्ट्रॉनिक्स एवं संचार अभियांत्रिकी)

एंटीना वायरलेस संचार प्रणालियों का एक अत्यंत अनिवार्य हिस्सा है। जैसे-जैसे ब्लूटूथ डिवाइस, रेडियो फ्रीक्वेंसी डिवाइसेस और ऐसे उपकरणों का आकार दिन-प्रतिदिन घटता जा रहा है, वैसे-वैसे वायरलेस डिवाइसेस की ज़रूरतें बढ़ती जा रही हैं। छोटे आकार के उपकरणों की आवश्यकता को पूरा करने के लिए, एंटीना को छोटे आकार के होने की आवश्यकता होती है और एंटीना को कई वायरलेस अनुप्रयोगों के लिए उपयोग किया जा सकता है, बिना एंटीना मापदंडों को प्रभावित किए। इसलिए अल्ट्रा-वाइडबैंड की अवधारणा का उपयोग किया जाता है। एंटीना के प्रदर्शन को बढ़ाने के लिए डिफेक्टेड ग्राउंड स्ट्रक्चर और स्लॉटिंग का उपयोग किया जाता है।

प्रस्तावित एंटीना को १.६ मिमी की ऊंचाई के साथ ३५× ३० मिमी^{२} के सब्सट्रेट आकार में डिज़ाइन किया गया है। एफआर-४ इपॉक्सी सब्सट्रेट ४.४ की वैधुत शीलता और .०२ के हानि स्पर्शरेखा का उपयोग किया हुआ है । मोनोपोल एंटीना प्राप्त करने के लिए ग्राउंड आकार को कम किया जाता है और बैंडविड्थ और लाभ के संदर्भ में एंटीना के प्रदर्शन में सुधार करने के लिए दोनों पैच के साथ-साथ ग्राउंड प्लेन पर स्लॉट्स काट दिए जाते हैं। प्रस्तावित एंटीना को एंसॉफ्ट एचएफएसएस सॉफ्टवेयर, पीसीबी डिजाइनिंग मशीन में गढ़ा और वीएनए का उपयोग करके परीक्षण किया गया है। प्रस्तावित एंटीना ३.१-१४.४५ गीगाहर्ट्ज़ बैंड में ११.३५ गीगाहर्ट्ज़ के बैंडविड्थ के साथ प्रतिध्वनित करता है इसके साथ- साथ ३.३१-३६ गीगाहर्ट्ज़ (वाईमैक्स) और ४.४-५.८ गीगाहर्ट्ज़ (डब्ल्यूएलएएन) के नॉचड फ्रीक्वेंसी बैंड के साथ लाभ २.१७ डीबी से ऊपर का है और पूरी आवृत्ति के दौरान दक्षता ८०-९० प्रतिशत है। प्रस्तावित एंटीना वायरलेस संचार के अनुप्रयोगों में वाईमैक्स और डब्ल्यूएलएएन बैंड के लिए कोई हस्तक्षेप नहीं करता साथ प्रस्तावित एंटीना यूडब्ल्यूबी आवृत्ति रेंज में अनुप्रयोगी है।

(पारस)
सलाहकार

(सुनील शर्मा)
लेखक