“DESIGN AND ANALYSIS OF MICROSTRIP PATCH ANTENNAS BY MULTI-CAVITY MODEL FOR VARIOUS WIRELESS APPLICATIONS”

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In

Wireless Communication

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DECLARATION

I hereby declare that the work presented in the thesis entitled "Design and Analysis of Microstrip Patch Antennas by Multi-Cavity Model for various Wireless Applications" is an authentic record of my study that has been carried out as per requirement for the award of degree of M.E. (Wireless Communication) at Thapar University, Patiala, under the supervision of **Dr. Jaswinder Kaur, ECED.** I also declare that the work embodied in the thesis has not been submitted to any other university/institute for the award of degree.

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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Asmita

ABSTRACT

The advent of Printed Circuit board technology (PCB) made Microstrip Patch Antenna a reality. The modern era belongs to wireless technology which has brought the world very close such that the universe also seems closer. The credit of making the world a small place goes to antennas. Antennas form the essential and the most indispensable part of communication system. One such antenna that has made the communication easier and hustle free is Microstrip Patch Antenna.

Being light weight, reliable, inexpensive, conformal and mechanically robust, they find their application in every next technology be it spacecrafts, aircrafts, radio detection and ranging systems, television, mobiles etc. No doubt they carry a blot of being low gain, narrow bandwidth and relatively large antennas, but the classical and regular patch antenna can be put into use by certain modifications like etching slots, stacking, using electromagnetic bandgap structures, lens covering etc. which make the regular patch antenna an unavoidable piece of technology. The advantages that this antenna embraces have constantly urged the researchers to do something new and innovative with it.

The present thesis work revolves around the theoretical analysis of the behaviour of the slotted patch antenna by multi-cavity model; the reason which makes the slotted patch antenna multi-resonant has been looked upon. Also a compact CPW fed patch antenna has been designed for the purpose of making it serviceable for wireless applications like WLAN, WiMAX and IMT. Computer Simulation Technology (CST) Microwave studio V’14 has been used to simulate the designs and fulfilling the aforesaid aims.

CONTENTS

LIST OF ACRONYMS

EBG	Electromagnetic Bandgap
WLAN	Wireless Local Area Network
WiMAX	Worldwide interoperability for Microwave access
IMT	International Mobile Telecommunication
CST	Computer Simulation Technology
VNA	Vector Network Analyser
VSWR	Voltage Standing Wave Ratio
CPW	Coplanar Waveguide
MHz	Mega Hertz
GHz	Giga Hertz
dB	Decibel
dBi	Decibel-isotropic
GPS	Global Positioning System
UMTS	Universal Mobile Telecommunications System
RFID	Radio Frequency Identification

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CHAPTER 1

INTRODUCTION

1.1 Research Motivation

Nowadays the world has become very small and even the universe seems to be thy neighbour. The recent developments in the wireless communication field have made the world closer and communication has become wire free. The information can be transmitted from one corner of the world to another via radio waves, microwaves, sonic waves, free space optical communication, electromagnetic induction etc. In order to carry out the communication, the utmost requirement is the availability of radio transceivers i.e. antennas. Antennas are an essential transitional structure between the guiding device and the free space that transmit the information from source to destination with the help of some form of energy as shown in Figure-1. There are different types of antenna configurations available which include wire antennas, aperture antennas, reflector antennas, log-periodic antennas, travelling wave antennas and microstrip antenna. Out of these the one that have constantly been the researchers' favourite is Microstrip Antennas.

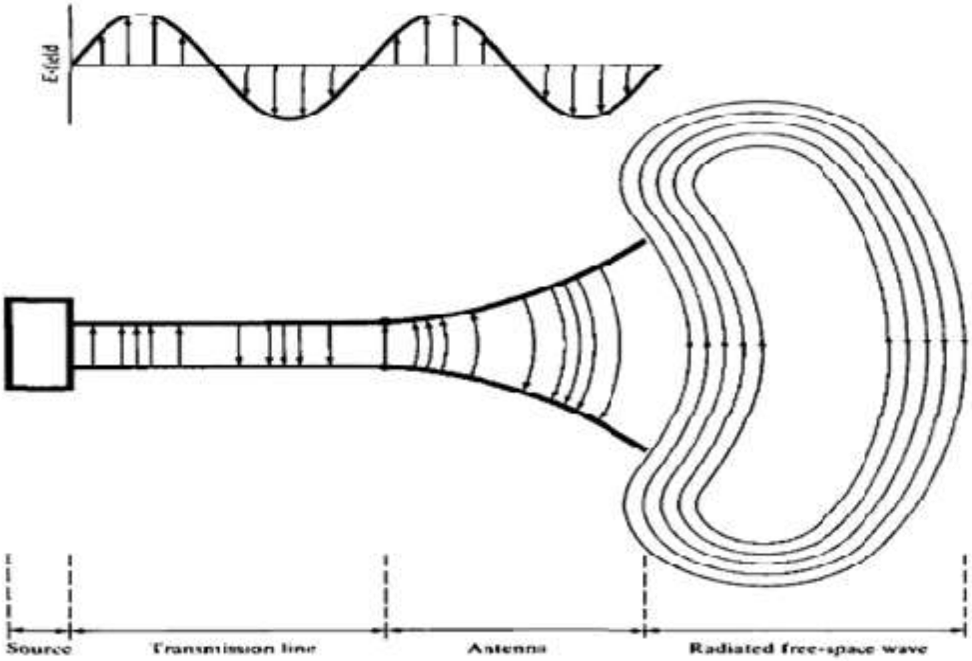


Figure 1.1: Antenna as a Transition Device [25]

The reason of them being under continuous research is their designer and user favourable qualities which include easy and inexpensive manufacturing, their light weight, easy integration with MMICs and low cost. But the classical patch antenna suffers from some disadvantages like low bandwidth, low gain and large size [25]. Hence in order to put the patch antenna into use, several modifications need to be done in its basic structure such that the end result is an antenna with higher bandwidth and gain and lesser size which can be easily incorporated in handheld devices. The various amendments through which the traditional patch goes through include stacking [5], cutting slots of various shapes like U, L, E [2], [3], [4], etc., using special feeds like coplanar waveguide feed which is lossy at low characteristic impedances [6], etching electromagnetic bandgap (EBG) structures [9], cavity blocking, lens structures and inductive & capacitive loading help in achieving the desired high gain, high bandwidth and a small sized patch antenna.

Also in order that the antennas cover much less space in the equipment, every possible step is taken to make them smart. It is done my making a single compact antenna functional for multiple applications by etching slots on the patch which lengthens the current path and different current distributions on a single patch make the antenna resonate for different frequencies.

Hence every researcher is engaged in inventing a novel design that overcomes all these disadvantages and proves to be useful in serving to the wireless applications like WLAN, WiMAX, IMT, and Bluetooth etc. Much work has been done in this regard which include a planar compact triple-band monopole antenna for WLAN/WiMAX; proximity-coupled microstrip patch antenna for Bluetooth, WiMAX and WLAN wireless applications; tri-band microstrip antenna with L-shaped slots for Bluetooth/WLAN/WiMAX; a multiband slot antenna for GPS, WiMAX, WLAN systems; compact and small planar monopole antenna with symmetrical L and U-shaped slots; compact modified swastika shape patch antenna; electrical characteristics of a dual-band microstrip patch antenna for GSM/ UMTS/WLAN operations; novel dual band multistrip monopole antenna with defected ground structure and many more which have not been written for the sake of brevity.

1.2 Review of Microstrip Antenna

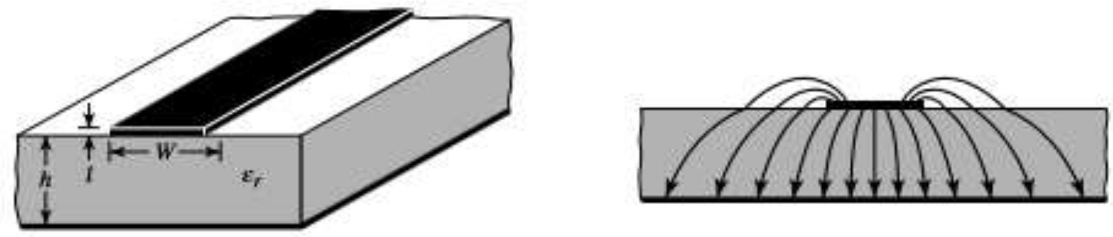
A microstrip patch antenna is a very common variety of printed antennas. It is formed by etching the antenna pattern on the metal trace of the printed circuit board (PCB) whose opposite side acts a ground plane for the antenna structure. The thin patch which acts as the radiating part of the antenna can take any continuous shape most common of which are rectangular, circular, triangular, elliptical, dipole etc. The PCB over which antenna pattern is etched acts as an insulating dielectric substrate. There is a large variety of materials available that can be suitably used as the substrate whose dielectric constant may vary from $2.2 \leq \varepsilon_r \leq 12$. But the ones that are mainly picked are the ones with lower dielectric constant value as they help in achieving larger bandwidth and loosely bound fields. Also thicker substrates help in achieving larger bandwidths but this comes with a disadvantage of increased surface waves that may affect the current distribution and polarization of the patch [25]. Some common examples of the substrate are Rogers RT Duroid 5880, FR-4 with their dielectric constant values as 2.2 and 4.4 respectively.

The microstrip patch antenna can be fed with the help of microstrip line feed, coaxial probe feed, coplanar waveguide feed (CPW), aperture and proximity coupling feed. Both the line feed and probe feed are easy to fabricate and simple to match but the asymmetries result in cross polarization and also the bandwidth is quite narrow. The CPW feed is the best candidate for achieving large bandwidths which is because of its lossy nature at low characteristic impedance values that results in lower value of the quality factor (Q) and hence higher bandwidth.

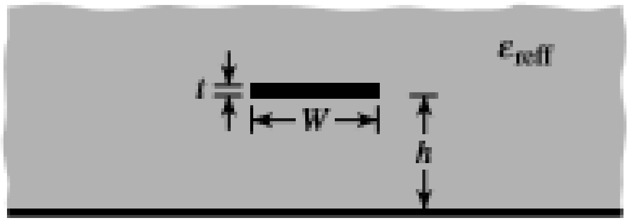
1.2.1 Analysis and Design Equations

Analysing an antenna is the most interesting and captivating part of the whole antenna design procedure. The transmission line model, the cavity model though approximate, yet help in getting a good physical insight of the antenna structure and help in understanding the behaviour of the antenna at a basic level. It becomes easier to anticipate the frequencies and helps in avoiding rugged hit and trial method to achieve the desired frequencies. Both the methods have been completely utilized in analyzing the designs that have been presented in this thesis work. The design equations mentioned below have been considered as given in [25].

The background and the base for the transmission line model is the fringing effect. Because of the finite length and width of the patch, the fields extend beyond the edges which are technically termed as fringing fields as shown in Figure-1.2(b). The effect of fringing fields must be taken into account as it affects the resonant frequency.



(a) Microstrip Line (b) Fringing Effect



(c) Effective Dielectric Constant

Figure 1.2: Microstrip Line and its Fringed Electric field Lines, and Effective Dielectric Constant Geometry [25]

Because of fringing the microstrip line seems to look electrically wider as compared to its actual dimensions. In order to account for the fringing and propagation of waves for the otherwise non-homogeneous line of two dielectrics, a homogenous line as shown in Figure-1.2(c) having single dielectric substrate is introduced whose effective dielectric constant ($1<\varepsilon_{reff}<\varepsilon_r$) is such that its electrical characteristics are same as that of the actual microstrip line of Figure-1.2(a). With the increase in the frequency this effective dielectric value $\varepsilon_{\mathrm{reff}}$ approaches towards ε_r with its initial static values given by the following equation for:

$$\frac{w}{h} > 1 \tag{1.1}$$

$$\varepsilon_{\mathrm{reff}} = \frac{\varepsilon_{\mathrm{r}} + 1}{2} + \frac{\varepsilon_{\mathrm{r}} - 1}{2}\left(1 + 12\frac{\mathrm{h}}{\mathrm{w}}\right)^{-\frac{1}{2}}$$

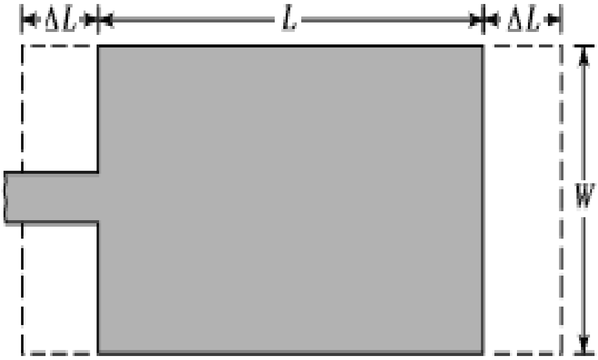


Figure 1.3: Effective length of the patch [25]

As can be easily seen from Figure-1.3, fringing gives an impression of increased electrical length of the patch such that effective length L_{eff} of the patch is taken as:

$$L_{\mathrm{eff}} = L + 2\Delta L \tag{1.2}$$

Where ΔL specifies the amount of increase in the length on each side and is a function of effective dielectric constant $\varepsilon_{\mathrm{reff}}$ and width to height ratio and is given by:

$$\frac{\Delta L}{h} = 0.412\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{1.3}$$

Hence the basic design steps include the determination of length (L) and width (W) of the patch that will let the antenna resonate for a particular desired frequency f_r as per equation 1.4 and 1.5:

$$W = \frac{v_o}{2f_r}\sqrt{\frac{2}{\varepsilon_r \quad + 1}} \tag{1.4}$$

$$L = \frac{1}{2\, f_r \sqrt{\mu_o\, \epsilon_o}\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{1.5}$$

As per the cavity model the fields within the substrate, which is bounded by electric conductors on the top and bottom and magnetic walls along the patch's perimeter, can be analysed more precisely by treating the region as a cavity. Only TM^x resonant modes are considered within the cavity because of the nearly perpendicular electric field to the patch's surface. The resonant frequency within the cavity is given by:

$$f_{mn} = \frac{c}{2\pi}\sqrt{\left(\frac{m\pi}{L}\right)^2 + \left(\frac{n\pi}{W}\right)^2} \tag{1.6}$$

where m and n specify the number of half cycle field variations along the length L and width W of the cavity. The occurrence of the resonant modes out of any antenna design depends upon the relation between the length and width of the patch. The following table summarizes the same:

TABLE I: SUMMARY FOR THE POSSIBLE RESONANT MODES

Dimensions	Dominant Mode	Next Higher Mode
If L>W>h Also if L>W>L/2>h But if L>L/2>W>h	TM10	TM01 TM20
If W>L>h Also if W>L>W/2>h But if W>W/2>L>h	TM01	TM10 TM02

Thus according to both the models, the two slots separated by the length of the patch account for the radiation coming out of the antenna, with both the sources having same current density magnitude and same phase thus adding up in a direction to the patch's normal and hence are termed as the radiating slots. Both the models together help in getting an approximate yet useful understanding of the patch antenna.

1.3 Research Objectives

- The first and the foremost objective of this research is to identify the reason behind the occurrence of the multiple resonances in a slotted patch antenna which covers the analysis part.
- Also the research objective includes the design and analysis of a miniaturized multifunctional microstrip patch antenna applicable for wireless applications like WLAN, WiMAX and IMT.
- Finally all the results obtained via simulation and theoretical analyses are to be compared with the fabricated antenna testing results.

1.4 Overview of the Thesis

The thesis is divided into 5 chapters. The gist of all the chapters has been outlined below:

Chapter2 includes the literature which has been surveyed upon to carry out the research work. It deals with the survey regarding the work done for analyzing the slotted patch antenna's multi-resonant behavior and various novel designs for wireless applications like WLAN, WiMAX etc.

Chapter3 presents an I, inverted T and a H shape rectangular slotted patch antenna. The epicenter of the research work is to justify the multi resonant behaviour of a slotted patch antenna by setting a parallelism between the simulated results and the theoretical analysis performed by equating the slotted patch to multiple cavities. This theoretical analysis helps in anticipating the resonant frequencies for a given length and width of the slot that is to be made in the patch. The simulation of the antennas has been done using Computer Simulation Technology (CST) Microwave Studio V'14. The designs have also been fabricated and tested using Agilent's Vector Network Analyzer (VNA) E 5071 C series.

Chapter4 includes the design and analysis of a miniaturized patch antenna for WLAN, WiMAX and IMT band applications. CPW feed has been used to energize the antenna and to exploit its quality of providing wider bandwidths. The design has also been theoretically studied using multi-cavity model described in the chapter 3. CST has been used to simulate the antenna and the fabricated design is tested using VNA E 5071 C series.

Chapter5 includes the conclusions made and the future scope that lies in extending the research work.

CHAPTER 2
LITERATURE SURVEY

2.1 Literature Survey

Bappadittya Roy et al. (2016)

In this paper the authors have presented a compact coaxial fed patch antenna designed for the purpose of WLAN and WiMAX applications. The design consists of a U-shaped patch and two open ended rectangular ground slots. The authors have exploited the concept of etching slots which helps in getting enhanced bandwidth and a maximum of 66.5% of bandwidth has been obtained by etching a slot near the lower edge of U-shaped patch. The antenna has been designed on 1.6 mm heighted FR-4 substrate having a dielectric constant of 4.4 by following four stages. First a 24.5 mm wide and 24 mm long rectangular patch is made. Secondly rectangular slots are etched on the ground plane which is the first step in getting enhanced owing to same resonance of the slot as that of the patch. Following this, the shape of the patch is modified to get a U-shape patch whose dimensions are optimized to get the best possible bandwidth. Finally a 15.5 mm long and 3 mm wide rectangular slot is etched below the U shape patch which is the final step in getting the desired bandwidth for making the antenna WLAN and WiMAX applicable.

In this paper, the authors have carried parametric study to understand the behaviour of the slots. Their dimensions and positions are varied to get the optimum value for the bandwidth and it has also been observed that the variation of slot lengths greatly affects the resonant frequencies because of changed impedance values. The antenna has been fabricated and tested using Vector Network Analyser. The antenna has ALSO been simulated on different substrates like Bakelite, Teflon etc. and it is concluded that FR-4 gives the best bandwidth out of all. Hence looking at all the experimental observations, one can conclude that loading the patch with slots greatly affects the behaviour of the microstrip patch antenna because of the changed impedances which helps in enhancing the bandwidth by optimizing certain parameters [24].

Arshad Wahab et al. (2016)

In this paper the authors have presented the design and performance analysis of WLAN and WiMAX applicable circular patch antenna fabricated on a 5 mm thick air substrate with full ground plane to get most of the electromagnetic waves back to the surface of the patch. In the designs proposed, the authors have loaded the circular patch with dual-U and tri-U slots. These dual and tri U shaped slots are responsible for achieving the required bands for the aforesaid applications. In this paper also, the authors have studied the behaviour of the various aspects of the design such as gain, the varying resonant frequencies by changing the dimensions of all the parameters which helped in getting optimum values of the length, width and position of the slots for getting the desired bands. The dual-U slot antenna covers a bandwidth of 0.27 GHz around 3.37 GHz and 3.64 GHz accommodating the WLAN application band and 0.47 GHz around 5.15 GHz to 5.62 GHz which accumulates both the WiMAX and WLAN standards. The tri-U-slot antenna has the bandwidth of 0.14 GHz from 3.61 GHz to 3.75 GHz at its lower band, thus feeding for WiMAX and IMT operations and the tri-U-slot antenna has the bandwidth of 0.66 GHz from 5.18 GHz to 5.84 GHz at its second higher band, which is applicable for WLAN and WiMAX band applications. Much higher gains of about 8-9 dBi have been obtained in simulations because of the usage of air as substrate and large dimensioned ground [23].

Nirmen Mahmoud et al. (2016)

In this paper, the authors have obtained the desired bands for Bluetooth, WLAN and WiMAX applications by incorporating four L-shaped slots into a rectangular patch made on 1.6 mm heighted FR-4 epoxy substrate. The frequency ranges of 2.122 GHz to 2.339 GHz, 3.384 GHz to 3.575 GHz, and 5.599 GHz to 5.776 GHz are covered by the -10 dB bandwidth, thus meeting the desired specifications of Bluetooth (2.4 to 2.485 GHz), WLAN (5.15-5.825 GHz) and WiMAX (3.3-3.6 GHz) applications. The authors have explained and thus exploited the physical meaning of etching slots on a patch. The slots which act as series or parallel filters thus passing or rejecting some of the frequencies as per their dimensions, have been used to get multiple bands. Rigorous hit and trial method has been employed here to get all the three bands simultaneously in one structure making the design to be multi functional. Thus it can be concluded that the incorporation of slots greatly affects the functionality of a regular patch antenna, thus making them an indispensable part of the patch antenna design technology [22].

Praveen V. Naidu et al. (2015)

In this paper, the authors have presented a very compact asymmetric coplanar strip fed multi band antenna. The design has been fabricated in such a way that it can be made applicable for Bluetooth and all WiMAX and WLAN bands applications and being very small i.e 13.75×26 mm^2 can be easily integrated in hand held devices for consumer applications. The design is an amalgamation of mirror-L shaped strips and two rectangular strips. The proposed structure covers a bandwidth of 200 MHz and 2800 MHZ which successfully covers the required band for serving 2.4/5.2/5.8GHz wireless local area network (WLAN) and 3.5/5.5 GHz WiMAX, and 2.4 GHz Bluetooth/ZigBee/RFID bands. In this paper, the authors have also proven the agreement that the measured results are in with the simulated results by simulating the antenna by taking the effect of the coaxial cable with SMA connector having same dimensions as that of the actual cable and connector. The negligible amount of current flowing on the outer conductor of the cable does not result in any unbalancing currents in the cable, thus making the measured results in good favour of the simulated ones. With the help of the parametric variation, the regions responsible of multiple frequencies are studied and equations for all three resonant frequencies are derived by looking at the length affecting a particular frequency. The technique of getting a compact ACS-fed antenna has been further validated by simulating an arc shape antenna [21].

Y. F. Cao et al. (2015)

This paper serves for presenting a four band patch antenna applicable for GPS, WLAN and WiMAX band applications. The antenna design consists of a rectangular slot, an inverted T-shaped stub, a T-shaped feed patch and two E-shaped stubs to generate four frequency bands at about 1.575 GHz, 2.45 GHz, 3.5 GHz, and 5.4 GHz for the GPS, IEEE 802.11b&g, WiMAX, and IEEE 802.11a systems, respectively. Each of the resonating frequency resulting from the antenna is because of a specific part of the design; hence the antenna cannot support MIMO feature for WiMAX. The T-shaped feed patch has been exploited to get two frequency bands. Then by incorporating a double folded stub, the whole structure then resonates well at four bands.

In this paper, the authors have tried to generalize their method of designing the structure by studying the behaviour of the antenna by parameter variation thus avoiding rigorous hit and trial for setting desired frequencies. Also the effect of the coaxial cable has been studied by simulating the antenna with the coaxial cable modeled by CST, such that now the simulated results are in better agreement with the measured results [20].

He Huang et al. (2015)

In this paper, the authors have propounded a microstrip-fed antenna for 2.4 GHz WLAN (2.4–2.484 GHz), 2.5 GHz WiMAX (2.5–2.69 GHz), 3.5/5.5 GHz WiMAX (3.4–3.69, 5.25–5.85 GHz), and 5-GHz WLAN (5.15–5.35 / 5.725–5.825 GHz) applications. Originally the antenna has been designed to resonate at 5.2 GHz. Then with the help of some metamaterial reactive loading and L-shaped slot, the antenna has been made capable of resonating at other desired frequency bands. The antenna so proposed is acting as a monopole as the ground structure is not involved in the radiation mechanism thus reducing the overall effective size of the radiation area. With the aid of single metamaterial cell, the antenna has been made to resonate in single y-direction at all resonating frequencies.

The antenna has 10-dB impedance bandwidths of 1.7 GHz (2.3–4 GHz) and 1.6 GHz (5–6.6 GHz), which cover all the WLAN and WiMAX bands. The measured gains are about 3.2, 2.38, and 2.34 dBi at 2.44, 3.5, and 5.5 GHz respectively. The main advantage of this design is its very compact size with an area of $12.9\times6.5\ \text{mm}^2$, making it a good candidate for employing in the hand held devices and other wireless systems [19].

Pritam Singh Bakariya et al. (2015)

Proximity coupled multiband Microstrip patch antenna has been proposed in this paper. The antenna has been so designed that it works at Bluetooth (2.4-2.485 GHz), WiMAX (3.3–3.7 GHz), and WLAN (5.15–5.35 and 5.725–5.85 GHz) bands. Two FR-4 layers, each 0.8 mm thick, have been employed to design the antenna. A buried rectangular strip in the middle layer is used to feed the V-shaped patch having a rectangular strip on the top layer by proximity coupling. To improve the antenna characteristics, resonating parasitic structures have been made on the back side of the antenna. A consistent radiation pattern with stable gain is an attractive feature of this antenna. Small cross-polarization and size makes the antenna suitable for applications demanding good polarization purity [18].

Mahdi Moosazadeh et al. (2014)

A rectangular patch loaded with L and U-shaped slots has been presented by the authors, on an FR-4 substrate having a permittivity of 4.4. It has been designed to work for WLAN and WiMAX band applications. In this paper also, the authors have done parametric study in order to make the antenna capable for resonating in the (2.4/5.2/5.8 GHz) WLAN and (2.5/3.5/5.5 GHz) WiMAX. The small size (15 ×15×1.6 mm^2) of the antenna as compared to the previous dual and tri-band monopole antennas makes it better from them. The triple bands for the aforesaid applications have been achieved with the help of a pair of symmetrical L and U- shaped slots. Approximate effective permittivity approach has been utilized in which the slots are cut in such a way that certain dimensions of them approximately approach to quarter of the wavelength for getting the desired frequency or reaching close to it. Gains in the range of 2–2.6, 2.6–3.2, and 2.5–3.8 dBi have been achieved from lower to high frequency bands. Due to the partial ground and small size of the slotted antenna, an omnidirectional radiation pattern has been achieved [17].

M. Samsuzzaman et al. (2014)

In this paper, a modified 40×40×1.6 mm^3 Swastika shaped compact rectangular patch antenna with extra slot and wide slotted ground with four extra slots has been proposed. The antenna operates over the frequency ranges of 950 MHz (2.28–3.23GHz), 660 MHz (3.28–3.94 GHz), and 1120 MHz (5.05–6.17 GHz) suitable for WLAN (2.4/5.2/5.8 GHz) and WiMAX 2.5/3.5/5.5 GHz applications. The dimensions and the positions of the slits provide a great help in getting the impedance match. The slit being exactly below the patch slot, induces capacitive effect to nullify the inductive effect of the patch and provides nearly resistive impedance. Peak gain of the antenna is 3.97 dBi at 2.44 GHz, 4.04 dBi at 3.40 GHz, and 3.25dBi at 5.98 GHz at the resonant frequencies. A nearly good omnidirectional radiation pattern has been achieved in the azimuthal plane and bidirectional pattern in elevation plane which helps in getting better transmission in multipath environment. Wider bandwidth, small size and higher gain with nearly omnidirectional radiation characteristics make it a good candidate for WLAN and WiMAX band applications [16].

Jaswinder Kaur et al. (2014)

The authors have presented a 60×70 mm^2 dual band Microstrip Patch Antenna applicable for WLAN, WIMAX, MIMO applications. The design is composed of two inverted L shaped strips constituting the radiating patch and a defected ground structure taking the shape of plus sign greatly improves the impedance bandwidth value of the design. The proposed antenna works at 3.34–3.54 GHz and 4.90–6.26 GHz bands with adequate bandwidth of 200 MHz and 1.36 GHz such that the designed so proposed effectively covers the aforesaid applications. Parametric study has been performed in order to get the optimal values of the parameters for achieving the best possible results. The values for impedance transformations ratio turn out to be 1:1.32 and 1:1.24 at 3.48 and 5.25 GHz, respectively indicating a very good match to the 50-ohm line thus giving the best results.

Also the authors have justified the use of FR-4 epoxy glass substrate by using four different substrates and the results show the best values for the S_{11} parameter for the FR-4 substrate. The current distributions were checked to investigate the region responsible for which resonance. The simulated and measured results give almost an omidirectional radiation pattern stating the gain to be uniform [15]

Jaswinder Kaur et al. (2013)

In this paper the authors have presented a 20×30 mm^2 dual-band multistrip antenna for various wireless applications i.e. WLAN, Bluetooth, WiMAX and IMT. The technique of defected ground structure has been employed to achieve the desirable dual bands. Reasonable impedance bandwidths of around 200 MHz (2.3–2.54 GHz) and 590 MHz (5.26– 5.85 GHz) in two operating bands has been achieved. It has been observed that using multristrip patch and defected ground structure has appreciably improved the bandwidth. VSWR turns out to be 1.19 and 1.012 and the impedance transformations ratio are 1:1.19 and 1:1.012 at 2.385 and 5.4 GHz, respectively, which indicate that the antenna is very well matched to a 50-ohm line allowing maximum power to be coupled. Due to its small size and good bandwidths, the proposed antenna can be integrated with microwave circuits for practical applications [14].

Huiqing Zhai et al. (2013)

In this paper, the authors have presented a 18×37×1 mm^3 triple band antenna suitable for WLAN and WiMAX band applications. The design consists of three circular arc shaped strips which look like human ear. Three distinct frequency bands are achieved with the help of these strips and the design has impedance bandwidths i.e. 400 MHz (2.38–2.78 GHz), 480 MHz (3.28–3.76 GHz), and 1000 MHz (4.96–5.96 GHz), which are well applicable for both 2.4/5.2/5.8 GHz WLAN and 2.5/3.5/5.5-GHz WiMAX bands. The antenna has good omnidirectional radiation characteristics and very stable gains at all the working frequency bands. Each strip is about a quarter of the guided wavelength long calculated at the resonating frequency which makes the overall design to be compact. The average gains turn out to be 2.13, 2.50, and 3.51 dBi for 2.5, 3.5, and 5.5 GHz bands showing that the antenna provides stable gains in the three frequency bands. Variation of the angle of each strip has helped in tuning and achieving of the bands for the above mentioned applications [13].

J. H. C. Morais et al. (2013)

This paper revolves around investigating the behaviour of a slotted patch antenna. It has been shown that length, width and the position of the slots greatly affects the behaviour of the antenna. An antenna with dimensions 66.17mm×40.59mm, on 1.8 mm thick FR-4 substrate has been used as reference. Investigations have been carried out by etching horizontal, vertical and angular slots on the rectangular patch. It has been observed that in horizontal slots, the resonant frequencies deviate according to its length and decrease with an increase in the length. In case of vertical slots, it is observed that the return loss values decrease with an increase in the slot length. Increasing the angular slots lets an increase in the resonant frequencies. The gain of the slotted antenna becomes better as compared to unslotted one [12].

Achmad Munir et al. (2013)

In this paper, the authors have investigated a technique for bandwidth enhancement by etching multiple slots on an 80×55 mm^2 patch antenna which has been designed for a center frequency of 1.6 GHz for Global Positioning System (GPS) application. A number of 13 slots are etched on the patch which are parallel to each other having unequal lengths all 2mm apart. Each slot has been approximately modeled by using a combination of LC series connected to another LC parallel producing bandpass filter’s characteristics. The patch has been approximated as a parallel RLC circuit such that resonant frequency depends upon the values of the L and C values. Thus the inductance of the patch changes upon etching slots on it. The increase in the inductance value decreases the quality factor which varies inversely with it. Thus the bandwidth of the structure increases as it varies inversely to the quality factor value. Hence the multiple slots technique improved the bandwidth of the reference antenna by 70.8% [11].

J. Cai et al. (2012)

A triple band, planar 20×30×1.5 mm^3 monopole microstrip patch antenna has been proposed by the authors for the WLAN and WiMAX band application. The design consists of an L-shaped strip and U-shaped slot. The antenna covers 2.33 GHz–2.51 GHz, 3.25 GHz–3.82 GHz, and 4.83 GHz–8.4 GHz bands, respectively, thus meeting the specifications of WLAN 2.4/5.2/5.8 GHz and WiMAX 3.5/5.5 GHz. The starting lengths of both L and U slot are approximated by equating it to quarter of the wavelength at the desired frequencies. The effect of using a defected ground structure has also been investigated. Parametric study has been performed in order to get the optimal values of the parameters for achieving the best possible results. Dimensions of the U and L part of the design are varied to check its effect on the antenna performance. Gains of 2.1 dBi at 2.4 GHz, 2.5 dBi at 3.5 GHz and 3.4 dBi at band from 5.2 GHz to 6.2 GHz are achieved. Nearly omnidirectional H-plane radiation pattern and bidirectional E-plane radiation characteristics have been obtained. The small size and good bandwidth makes it suitable for employing for practical purposes [10].

M. Gujral et al. (2012)

In this paper the authors have tried to evolve some method to remove the basic disadvantage of the patch antennas of having narrow bandwidth taking 8×6.3 mm^2 reference antenna. It has been done by etching an electromagnetic band gap structure (EBG) on the feed line. 48.8% increase in the bandwidth is observed with resultant 0.381 GHz versus the actual bandwidth of 0.256 GHz without EBG. It is so because the electromagnetic band gap structures are meant to suppress the unwanted surface waves and helps in better impedance match. Comparisons reveal that etching EBG on the feedline does not let the current to spread out; rather it becomes focused to supply energy to the radiating surfaces. The overall gain of the structure also improves with this technique [9].

F. Li et al. (2010)

In this paper the authors have presented a novel CPW-fed triple-band monopole antenna designed by embedding an S-shaped meander strip into a C-shaped for WLAN and WiMAX applications. Bandwidths of about 110MHz centered at 2.45GHz, 310MHz centered at 3.55GHz, and 39% ranging from 4.1 to 6.2GHz, covering the required bandwidths of 2.4/5.2/5.8GHz WLAN and 3.5/5.5GHz WiMAX standards have been obtained. Various parametric studies have been done to analyze the behaviour of the antenna. Average gains of 2.8 dBi (2.75–2.85 dBi), 3.23dBi (3.18-3.27 dBi) and 3.6 dBi (3.4–3.8dBi) for the 2.4, 3.5 and 5.5 GHz operating bands have been obtained. Stable gains in the required bands and good radiation pattern makes the design very promising [8].

Adenen Rajhi1 et al. (2010)

In this paper the authors have designed an antenna for GSM/UMTS/WLAN applications. Two patch antennas with rectangular slots have been designed, such that the simulations result in three resonant frequencies. The authors have investigated that the second and third resonant frequency changes with the optimum slot position with respect to the feed location. Transmission and cavity model have been utilized to analyze the behaviour of a slotted patch antenna. The reason for multi resonant behaviour has been investigated and the presence of multiple subsections after etching slots has been attributed to be the cause for the birth of multiple resonating frequencies in a slotted patch antenna. A frequency range of 890 to 995 MHz is obtained for the GSM 900 resulting in an impedance bandwidth of 105 MHz. An operating frequency range of 1900 to 3100 MHz is obtained for UMTS 2000 and WLAN standard letting the impedance bandwidth to reach 1200 MHz [7].

Xiaodi Song et al. (2009)

In this paper the authors have proposed a small CPW fed monopole patch antenna in three service bands of 2.4–2.48, 5.15–5.35, and 5.725–5.825 GHz WLAN technology. The antenna's overall size is 40×100×0.81 mm^3. The input impedance bandwidths of 510 MHz from 2.28 to 2.79 GHz, 430 MHz from 4.89 to 5.32 GHz, and 460 MHz from 5.71 to 6.17 GHz have been measured. The monopole like radiation pattern characteristics makes the antenna suitable for wireless local area network (WLAN) band applications [6].

H. F. Abu Tarboush et al. (2009)

In this paper the authors have performed stacking of the patch antenna along with etching slots in the ground plane in order to investigate the amount of the effect that occurs on the impedance bandwidth of the antenna. A 30×90 mm^2 dimensioned patch on Roger RT/duroid substrate has been made. Before etching any slot or stacking the antenna, the bandwidth was near to negligible around the center frequency of 2.5 GHz. But after the introduction of the slot and stacking the patch improved the bandwidth by 25%. It is so because the stacking results in an increase in the thickness of the substrate thus letting the bandwidth to increase and the antenna becomes suitable for the wireless applications ranging between 2.5 to 3.19 GHz [5].

Raj Kumar et al. (2009)

This paper identifies the effect of etching slots on various parameters like resonant frequency, gain, impedance bandwidth and side lobes. Investigations have been done on a patch antenna designed to operate at 2.42 GHz. After performing various parametric variations, it has been concluded that upon increasing the width and length of the slot, the resonant frequency shifts to the lower side which is due to the increase in the inductance value. Also a good improvement is seen in the bandwidth which increases because of the decreasing value of the quality factor. Slight variations in the gain and side lobe level are observed due to the slots etched in the ground and the variations are more pronounced when the slots present in the patch observe some variations in their dimensions [4].

G. F. Khodaei et al. (2008)

An asymmetric U-slot patch antenna with lower diameter of the probe has been presented by the authors. It has been shown that reduction of bandwidth occurs by reducing the diameter of the probe from 2.5 mm to 1.27 mm when a symmetric U-slot is placed. It is because of the decrease in the S_{11} parameter value also. But still the main feature of the structure is the maintenance of the bandwidth within 30 % as compared to reference antenna despite having lower value of the probe diameter. But by placing the U-slot asymmetrically, it has been shown that despite having lower value of the probe diameter, the bandwidth does not get reduced and even larger value of the bandwidth is achieved compared to the previous reference antenna. The antenna so proposed can be employed in the applications when only cross polarization is used because it has high cross polarization levels in linear polarization applications [3].

B.-K. Ang et al. (2007)

A wideband E-shaped patch antenna for 5.25 GHz has been proposed by the authors that serve for the wireless applications in the 5-6 GHz range. A local inductive effect has been introduced to disturb the current distribution pattern which gives rise to another resonating mode around 5.8 GHz. Coupling of both the resonating modes results in a wideband. A detailed parametric study has been taken into consideration in order to understand the behaviour of the antenna and to get the desired optimum values. A bandwidth of 830 MHz covering 5.05 GHz to 5.88 GHz is achieved. Broadside directional radiation patterns are observed for both E and H-planes. For the entire frequency range, a gain of 7.17 dBi is obtained having ripple less that ±0.6 dB. The compactness, wide bandwidth and higher gains make this design suitable for implementing in the wireless equipments [2].

CHAPTER 3

APPROXIMATION OF MULTI-RESONANT BEHAVIOUR OF SLOTTED PATCH ANTENNA VIA MULTI-CAVITY MODEL

3.1 Introduction

The modern era belongs to wireless technology and the appetite for petite systems and high-speed communication has soared in the recent years. Printed antennas are compact and quite inexpensive, thus making them serviceable for the consumer applications. But the simple and traditional patch antenna has some drawbacks like narrow bandwidth and low gain that impedes its use in its original form. Several methods like stacking of patch antenna [5], etching electromagnetic band gap structures (EBG) structures [9], and different feeding techniques like coplanar waveguide feed (CPW) are used for broadbanding the antenna for achieving higher data rates. Literature identifies that the insertion of slots of various shapes into the patch effectively enhances the bandwidth of the respective antennas and enables them to operate at multiple frequencies thus making a single antenna functional for multiple applications [11]. Various parametric studies are performed by researchers to understand the dependence of the frequencies on length, width and position of slots or strips present in the design as done in [2], [4], [8], [10], [17] and [21] for instance.

The main aim of the work mentioned in this chapter is to identify the reason behind the occurrence of the multiple resonant frequencies that result from loading the patch with slots. For this a rectangular patch has been loaded with I, inverted T and H shape slots. The theoretical analysis has been done by using transmission line and cavity model that somehow explains and aids in foreseeing the frequencies around which the slotted patch will be resonating. Also the inability of the cavity model in narrating the presence of the surface waves, feed effect that mis-shapes the surface current, thus making some of the frequencies obsolete has been highlighted.

3.2 Theoretical Background, Antenna Design & Fabrication

In order to get some physical cognizance of the antenna, the transmission line and cavity model come to rescue. Both the models being simple and basic give approximate yet useful insight of the structure. As per the transmission line model, the patch antenna is represented by two slots set apart by a transmission line of length L which resonates because of the fringing fields thus increasing the effective length of the rectangular patch. The cavity model considers the two conductive surfaces separated by a dielectric substrate of permittivity ε_r and upon excitation the cavity becomes resonant. Hence taking both the concepts forward, a slotted patch antenna can be thought of as multiple cavities such that each subsection as per its own effective length, width and effective dielectric constant is merely two slots separated by a transmission line of specified effective length resonating according to the following formulaes:

$$L_{eff(sub)} = L_{sub} + 2\Delta L_{sub} \tag{3.1}$$

where, $L_{eff(sub)}$ is the effective length of each subsection of patch and ΔL_{sub} specifies the respective increase in length of each subsection due to fringing process in the patch which is given by:

$$\frac{\Delta L_{sub}}{h} = 0.412\frac{\left(\varepsilon_{reff(sub)} + 0.3\right)\left(\frac{w_{sub}}{h} + 0.264\right)}{\left(\varepsilon_{reff(sub)} - 0.258\right)\left(\frac{w_{sub}}{h} + 0.8\right)} \tag{3.2}$$

where, w_{sub} specifies the effective width of the subsection and $\varepsilon_{reff(sub)}$ is the effective dielectric constant for the respective subsection with given effective length and width and is given by:

$$\varepsilon_{reff(sub)} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{w_{sub}}\right)^{-1/2} \tag{3.3}$$

Thus dividing the whole patch area into different subsections of particular length and width with specific effective epsilon with each subsection accountable for particular frequency depending upon the mode becomes the basis for the presence of multiple resonant frequencies in a slotted patch antenna structure according to the following formula i.e.

$$f_{mn} = \frac{c}{2\sqrt{\varepsilon_{reff(sub)}}}\sqrt{\left(\frac{m}{L_{eff(sub)}}\right)^2 + \left(\frac{n}{W_{(sub)}}\right)^2} \tag{3.4}$$

where, m and n specify the number of half cycle field variations across effective length and width of the sub-cavity. The S_{11} parameter has been calculated as specified in [7] with the final equation given below where Y_{in} specifies the input admittance at the radiating edge and Z_o is the characteristic impedance of the line.

$$S_{11} = \frac{Y_{in}Z_o - 1}{Y_{in}Z_o + 1} \tag{3.5}$$

In order to verify this concept and to know the extent to which theory helps in predicting the frequencies, three different slotted patch antennas are presented. For this firstly a basic rectangular patch is made with Lp×Wp = 23.46 mm×30.429 mm on FR-4 epoxy substrate of dielectric constant 4.4, tan δ = 0.0024 and h = 1.524 mm at 3 GHz and is coaxially fed with inner and outer diameter of conductor 0.49 mm and 2.817 mm respectively. This configuration is loaded with slots for further investigations.

A. I-shape Slotted Patch Antenna

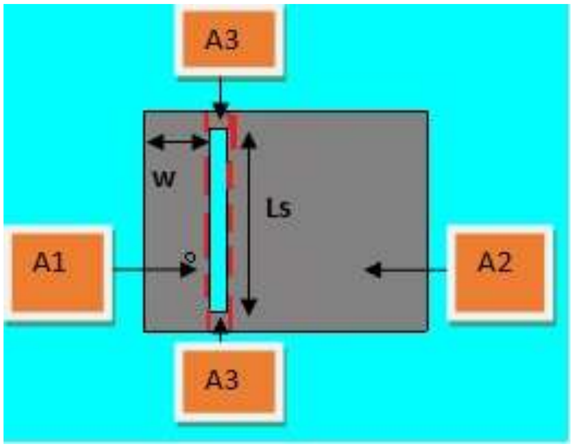


Figure 3.1: Areas defining I-shape Slotted Patch

Figure-3.1 represents a patch loaded with a slot pertaining to english alphabet I's shape. The length Ls of the slot is 19.46mm and is present at a distance of w = 7mm from the edge of the patch. Hence it is clear from the figure above that this structure can be divided into four sub regions that have been labeled as A1, A2 and A3 with length and width dimensions given as (23.46, 7) mm, (23.46, 21.429) mm and (2, 2) mm respectively whose individual frequencies will make the whole structure act as multi resonant.

Figure 3.2: Fabricated I-shape Slotted Antenna

B. Inverted T-shape Slotted Patch Antenna

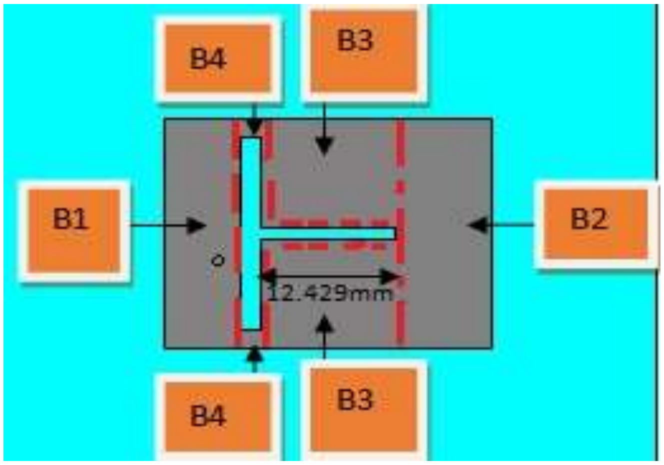


Figure 3.3: Areas defining Inverted T-shape Slotted Patch

This antenna structure is constructed by further manipulating the previously defined antenna thus giving a resemblance to alphabet T (inverted) as shown in Figure-3.3. This results in an increase in the number of areas as the region A2 gets splitted into two halves thus changing the current distribution of the region. The new regions are identified as B1, B2, B3, and B4 with the dimensions of (B1, A1) and (B4, A3) same. The length and width of the region B2 is 23.46 mm and 9 mm and that too for B3 is 11.23 mm and 12.429 mm respectively.

Figure 3.4: Fabricated Inverted T-shape Slotted Antenna

C. H-shape Slotted Patch Antenna

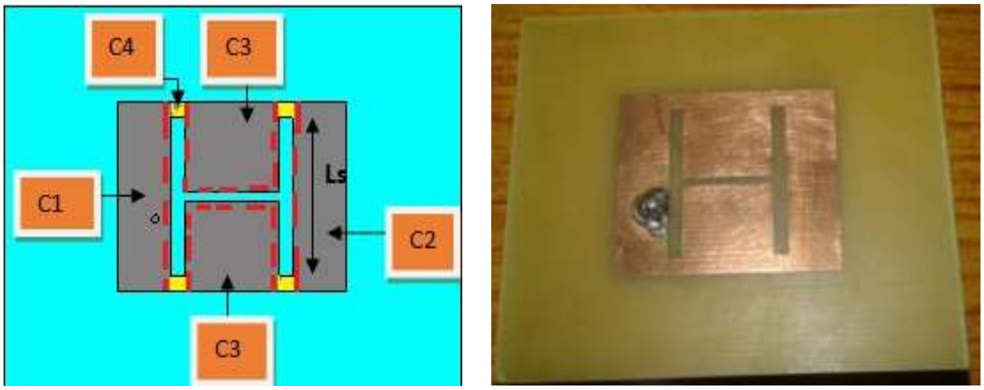


Figure 3.5: Areas defining H-shape Slotted Patch & Fabricated Design

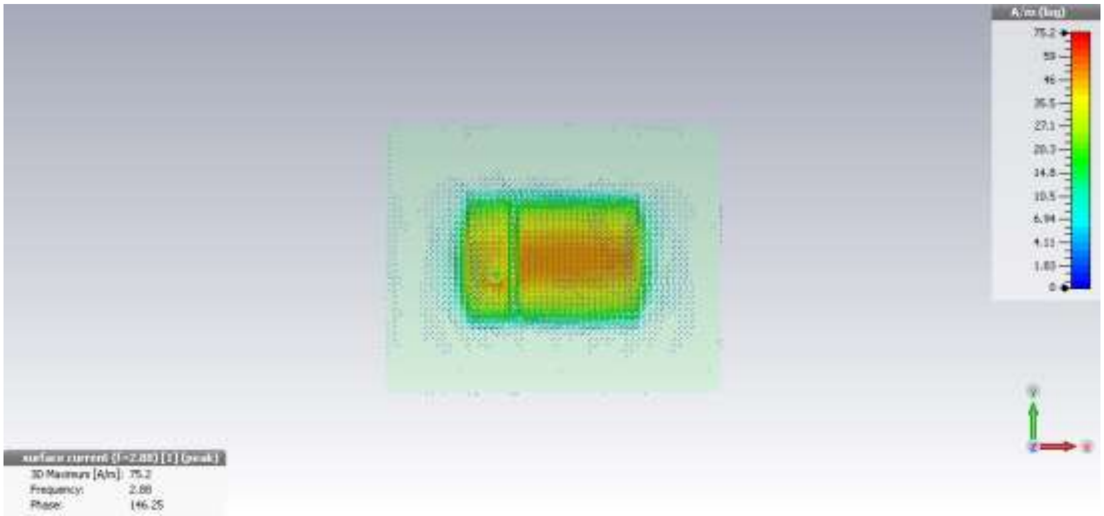
Finally an H-shape slotted patch antenna has been constructed resulting in the regions C1,C2,C3 and C4 as specified in the Figure-3.5 with the dimensions of (B1,C1,C2), (B3,C3) and (B4,C4) identical. Also all the yellow coloured regions depict the region C4. After getting a visualization of the various sub-regions of all the three antennas, the next section focuses on the comparison and relation between the frequencies resulting from the theoretical consideration and the simulated ones.

3.3 Simulated, Measured & Theoretical Results with Comparisons and Discussions

A. I-shape Antenna

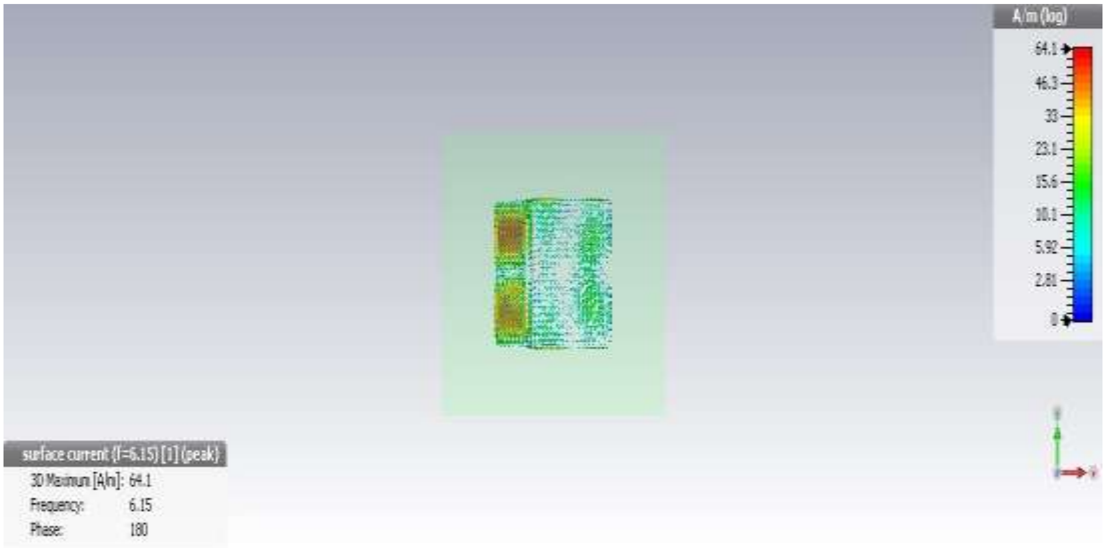
As has been specified that this antenna structure possesses four different regions. The sub-cavity A1 as per its dimensions ($L_{sub} > L_{sub}/2 > w_{sub} > h$) has TM10 as its dominant mode according to which it should have a resonating peak at about 3.19 GHz theoretically which is almost equivalent to the resonating frequency of the main cavity 3 GHz that shows its presence at 2.88 GHz while simulation. The surface current distribution of the patch as shown in Figure-3.6(a) specifies the contribution of the region A1 at this resonance. Owing to its dimensions, the region A1 also resonates well at its next higher mode i.e. TM20 at a frequency of 6.15 GHz which being almost equivalent to its theoretical counterpart 6.38 GHz indicates its presence due to the region A1. This can also be inferred from the surface current distribution of the patch at 6.15 GHz which shows that the region responsible for this resonance is A1 as shown in Figure-3.6(b).

Now as per the dimensions of the sub-cavity A2 ($L_{sub} > w_{sub} > L_{sub}/2 > h$) the length being dominant and also twin to that of the main cavity's length lets this sub cavity to resonate at the same frequency theoretically as well as during simulation as that of the main cavity i.e. 3 GHz which is showcasing its presence in the graph in Figure-3.7(a) at 2.88 GHz. Also the surface current distribution of the patch in Figure-3.6(a) justifies the participation of the region A2 in giving this resonance along with the region A1. Now as the width of this sub-section is greater than half of its length, the second mode being TM01 accounts for the presence of a resonance at 3.5 GHz theoretically and physically at 3.655 GHz which is also getting proven by its surface current distribution in Figure-3.6(c). Finally the region A3 with very small dimensions should resonate at extremely high frequency of about 41 GHz which is outside the purview. Thus in view of the results and the discussions regarding I-shape slotted patch, an inference can be easily drawn that loading the patch with this single narrow slot hardly disturbs the resonant frequency of the TM10 mode of the unslotted patch [1]. Also Figure-3.7(b) represents the comparison between the simulated, theoretical and the result obtained from testing the fabricated antenna. The graph clearly shows that the multiple frequency anticipation and justification process via theoretical analysis is a great helping tool and helps in approximating at least 65-70 % of the antenna's behaviour on paper.



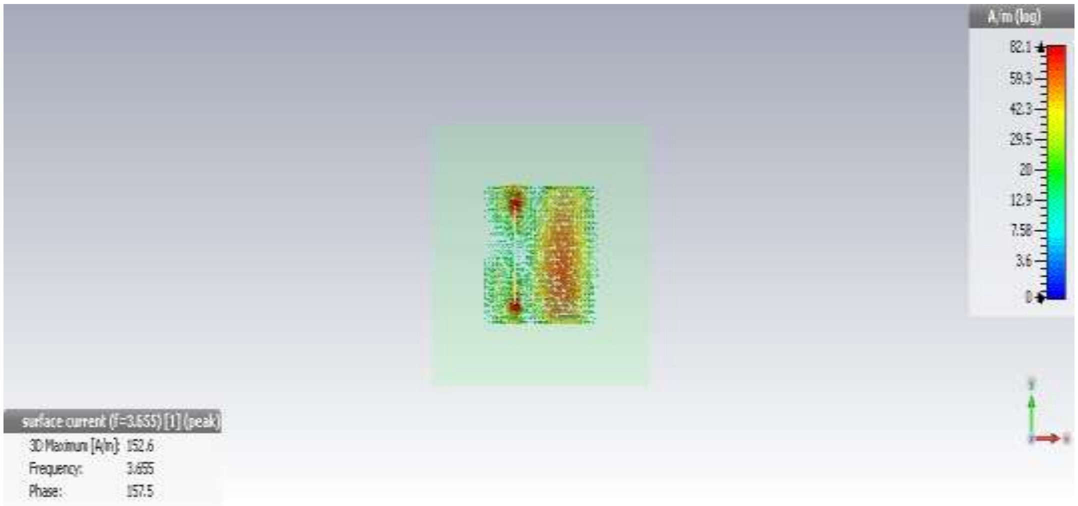
surface current (f=2.88) [1] (peak)
3D Maximum [A/m]: 75.2
Frequency: 2.88
Phase: 146.25

(a) Current Distribution at 2.88 GHz



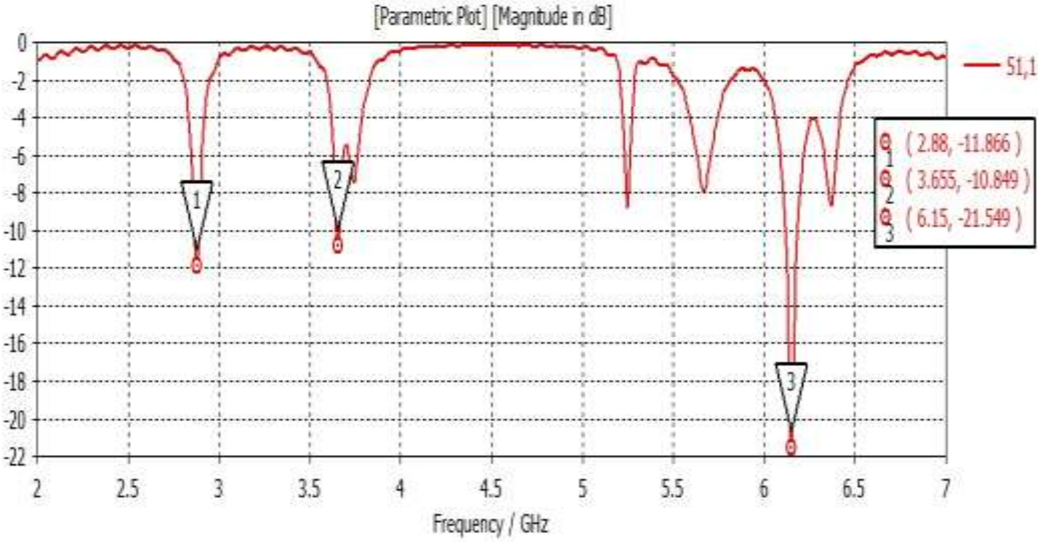
surface current (f=6.15) [1] (peak)
3D Maximum [A/m]: 64.1
Frequency: 6.15
Phase: 180

(b) Current Distribution at 6.15 GHz

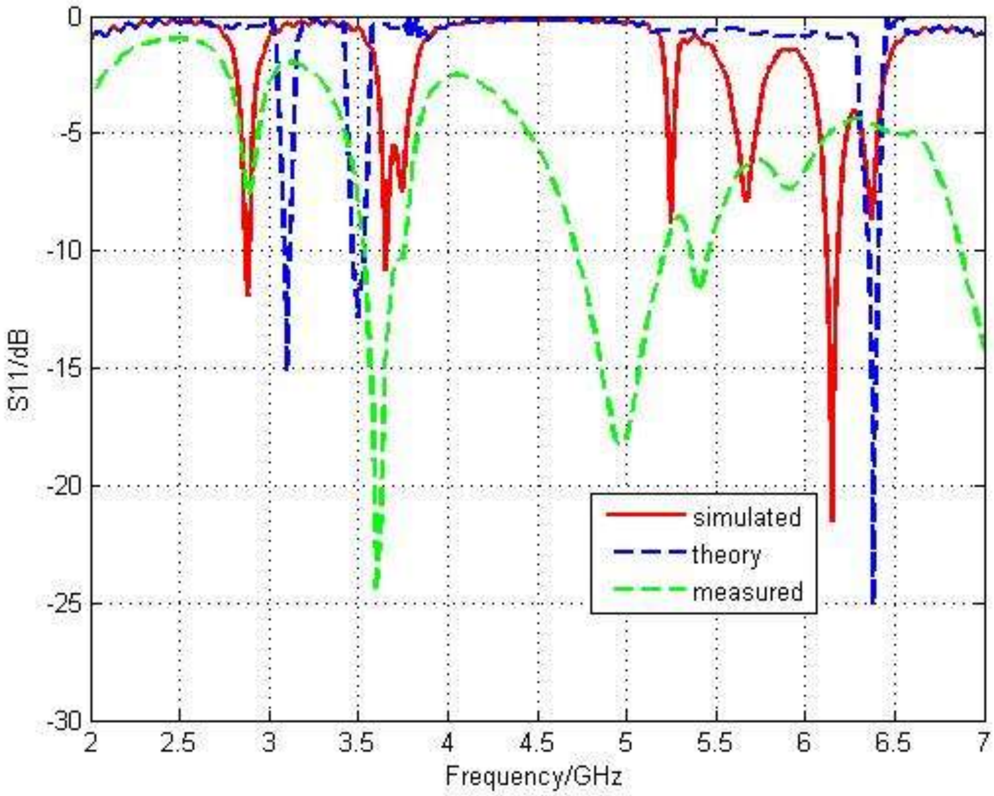


(c) Current Distribution at 3.655 GHz

Figure 3.6: Current Distribution results for I-shape slotted patch



(a) Simulated S_{11} parameter graph of I-shape Slotted Patch.

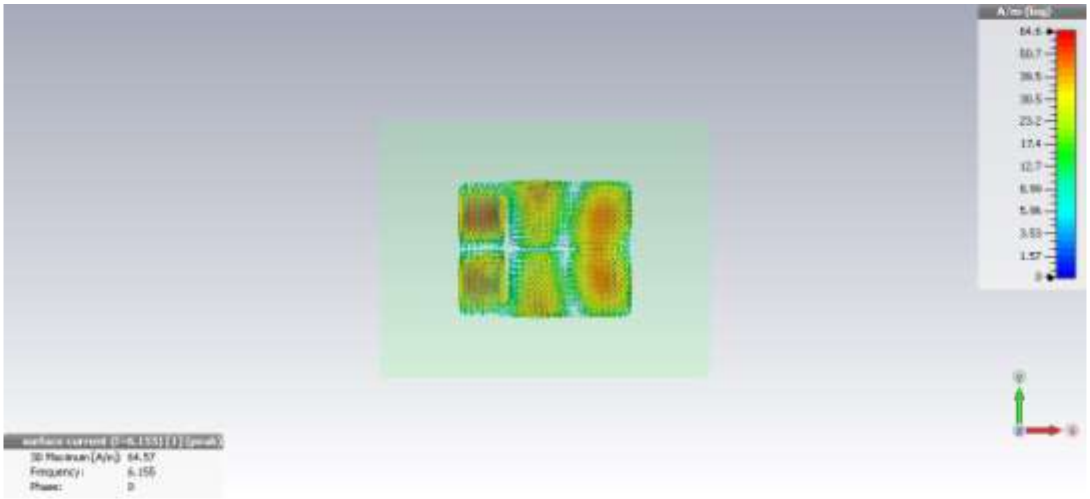


(b) Comparison between the simulated, theoretical and measured S_{11} parameter graphs

Figure 3.7: S_{11} parameter results for I-shape Slotted Patch Antenna

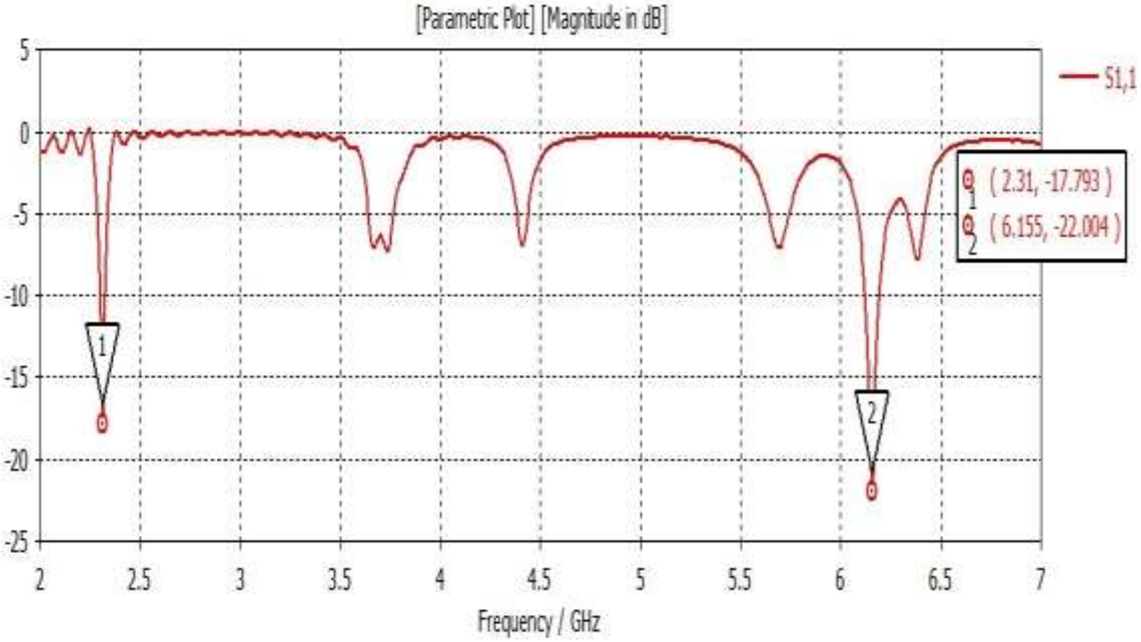
B. Inverted T-shape Antenna

As can be discerned from Figure-3.3, this slotted structure is composed of six regions out of which B3 and B4 sub sections have their replicas, thus reducing the total number to four. The sub-section B1 being dimensionally identical to region A1 of I-shape slotted patch antenna manifests the same behaviour and thus resonates well at 6.155 GHz in TM20 mode which, along with the surface current distribution in Figure-3.8, vouch for region B1 being responsible for this resonance. Considering the region B2 ($L_{sub} > L_{sub}/2 > w_{sub} > h$), whose frequencies are dominated by the length of the subsection should have its dominant mode resonating at about 3.1 GHz which is equivalent to that of main cavity's frequency. But as the literature specifies that upon increasing the length of the slot, the resonant frequency starts decreasing upon the increase in the inductance value. Therefore the sub-sections B1 and B2 whose dimensions account for the dominant mode resonance at 3.1 GHz actually resonate at 2.31 GHz frequency when the final length (tl) of the slot approaches to 12.429mm which is clearly visible in Figure-3.9(b), thus somehow limiting the power of cavity model. Also owing to B2 region's dimensions, a second order mode i.e.TM20 should provide a resonance at 6.3 GHz theoretically which does get justified by its simulated counterpart 6.15 GHz and the surface current distribution in Figure-3.8 which endorses for this subcavity's contribution in giving this resonance. In accordance to its dimensions, the region B3 ($w_{sub} > L_{sub} > L_{sub}/2 > h$) should have its dominant TM01 and second order TM10 mode resonating at 6.2 GHz and 6.1 GHz theoretically. The region B4 holds the same explanation as that of that of the sub-section A3 of I-shape slotted patch. Thus looking at the frequencies obtained theoretically for all sub-cavities and the surface current distribution of Figure-3.8 which is clearly showing that all the sub sections are contributing for frequencies around 6 GHz, the comparative analysis states that as per theory this T-shape patch should give a somewhat wideband around 6.2 GHz which as per simulation is resonating at a universal frequency of about 6.15 GHz. Also in Figure-3.9(c), the measured results depict the shift in the main cavity's frequency on left upon the introduction of new slot owing to increased impedance and also marks the commencement of the formation of a wide band shifting near to 6 GHz as compared to the measured results of I-shape patch thus somehow supporting the theory as well as simulated results.

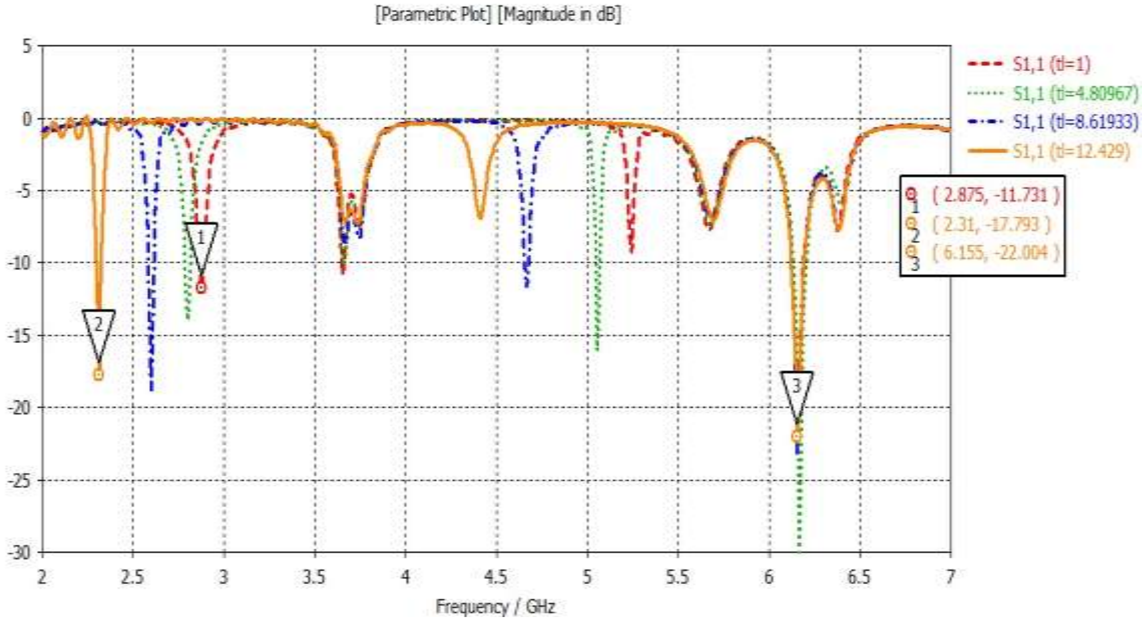


surface current (f=6.155) [1] (peak)
3D Maximum [A/m]: 64.57
Frequency: 6.155
Phase: 0

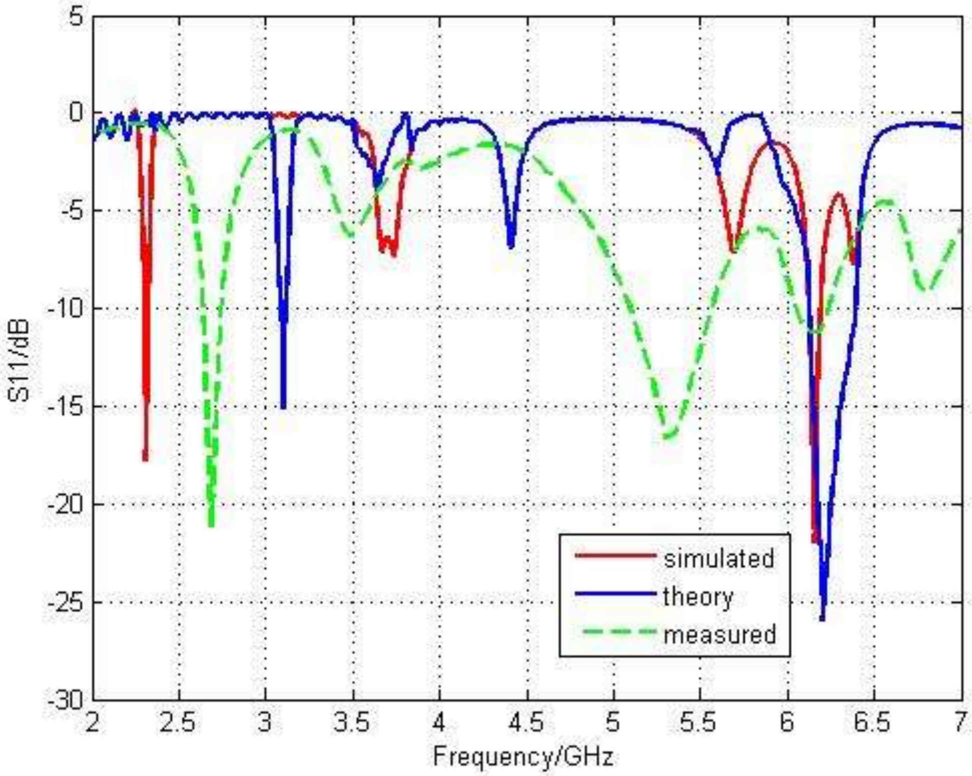
Figure 3.8: Current Distribution at 6.155 GHz.



(a) Simulated S_{11} parameter graph for inverted T shape patch.



(b) Figure showing decrease in resonating frequency upon increase in slot length tl: – – – tl=1mm; ... tl=4.8096; –.– tl=8.619; —tl=12.429.

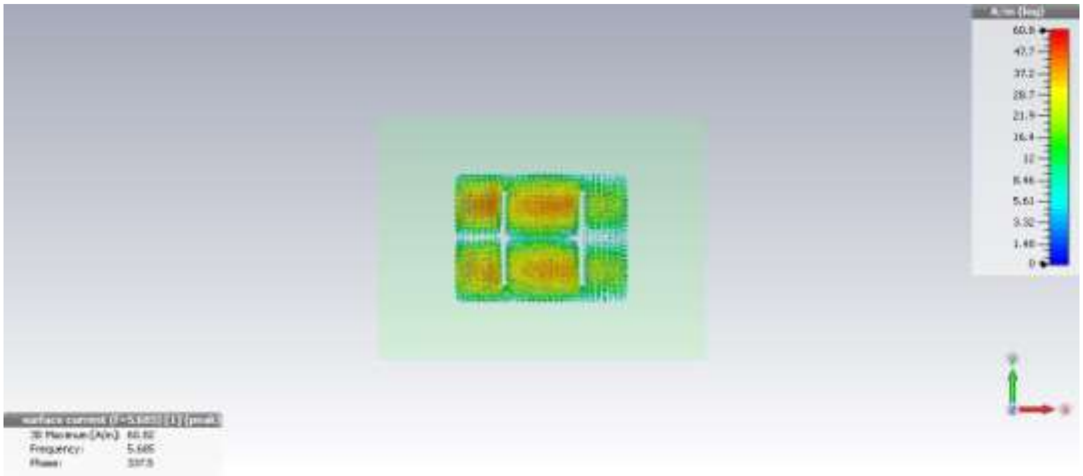


(c) Comparison of simulated, theoretical and measured S_{11}-parameter graphs

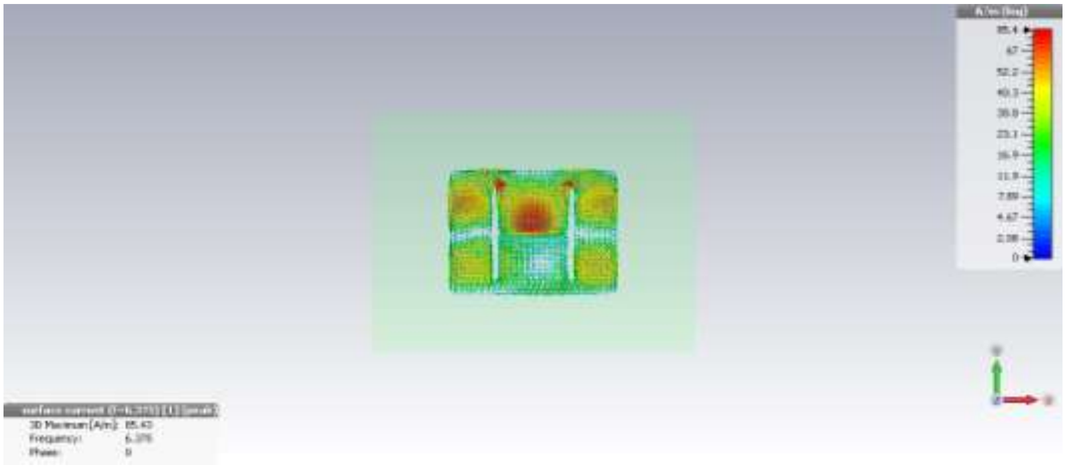
Figure 3.9: S_{11} parameter results for Inverted-T shape Slotted Patch Antenna

C. H shape Antenna

This structure which is mainly composed of C1, C2 and C3 sub-cavities, stands witness to some of the inabilities possessed by the cavity model. As is explained by many researchers that incorporating a slot in a patch increases the length of the current's path, thus lowering the resonant frequency. Similar activity can be observed here also in Figure-3.11(c) where the universal center frequency of about 6.15 GHz that should occur while simulation from the sub-cavities C1, C2 and C3 because of almost same dimensions as that of inverted T shape patch, has now shifted towards left upto 5.68 GHz upon the introduction of the final arm thus forming an H shape slotted patch and the patch gives a new resonance at 6.375 GHz. As per the theoretical results there should be a wideband around 6 GHz that may result from (6.1, 6.2, 6.3) GHz of frequencies emerging from different sub-sections. This gets proved by the presence of a wideband near 6 GHz in measured results of Figure-3.11(b) thus supporting the theory which predicts the presence of a wideband around 6 GHz because of the frequencies so obtained theoretically for every sub-cavity. Also the surface current distribution in Figure-3.10 does give an indication that patch can be responsible for giving a wideband or multiband around 5.68 GHz and 6 GHz practically because of the sections supporting both the frequencies. The moment of truth for the multi cavity model comes at this stage where it crashes and we get one extra resonance at 3.69 GHz against the theory during simulation as well as in measured results. It may have occured due to even higher modes or impedance mismatching because of the loading of the patch with slots which the model does not point about. Also the frequency of the main cavity finally becomes obsolete with this structure thus delimiting the use of this model.

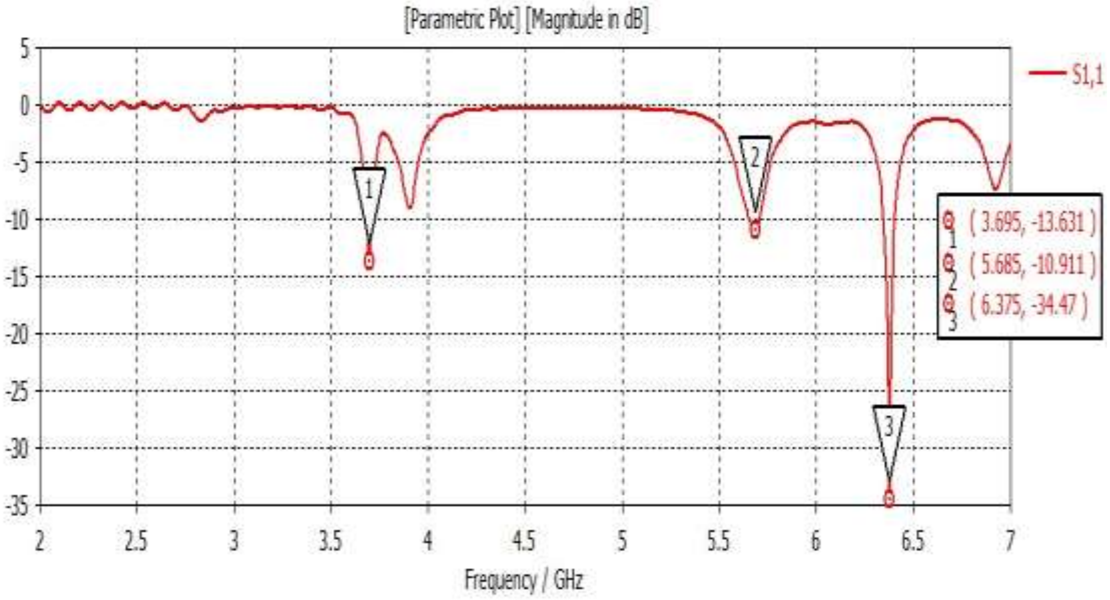


(a) Current distribution at 5.685 GHz

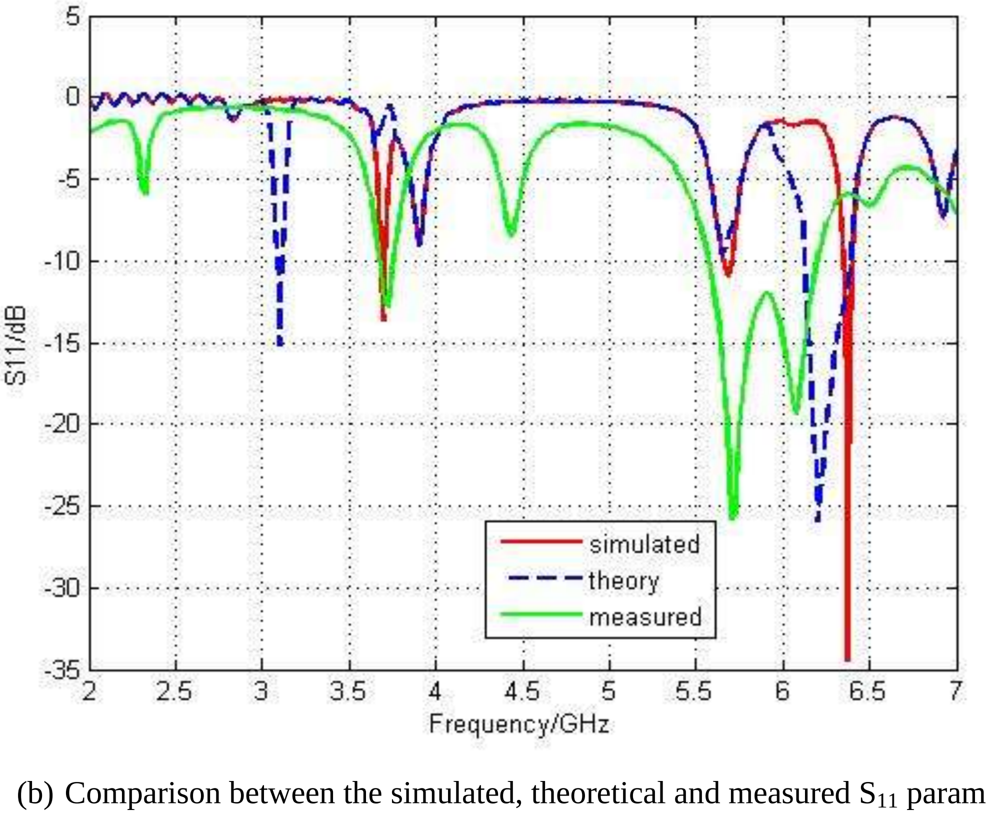


(b) Current distribution at 6.375 GHz

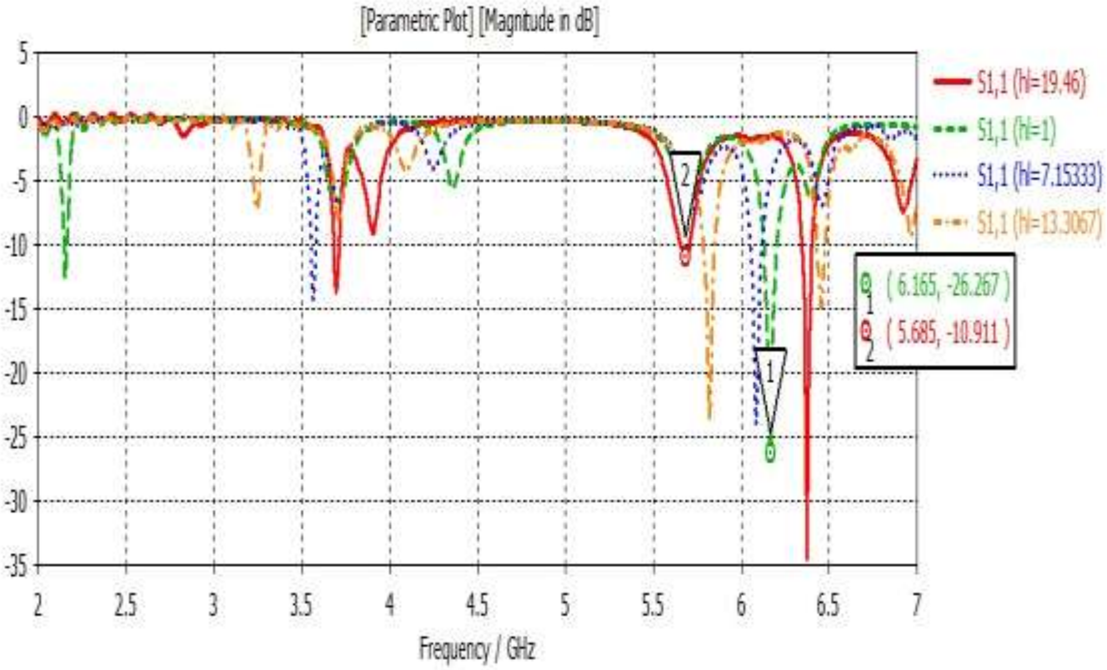
Figure 3.10 Current Distribution results for H-shape slotted patch



(a) Simulated S_{11} parameter for H-shape patch



(b) Comparison between the simulated, theoretical and measured S_{11} parameter



(c) Figure showing decrease in resonating frequency upon increase in slot length

hl: – – – hl=1mm; ... hl=7.153mm; –.– hl=13.31; —hl=19.46

Figure 3.11: S_{11} parameter results for H-shape Slotted Patch Antenna

The results for all the three antennas have been summed up in the following tables:

TABLE II COMPARISON FOR I-SHAPE PATCH

Region	Theory	Simulated
A1	TM10=3.193GHz TM20=6.386GHz	TM10=2.880GHz TM20=6.150GHz
A2	TM10=3.000GHz TM01=3.522GHz	TM10=2.880GHz TM01=3.655GHz

TABLE II COMPARISON FOR INVERTED T-SHAPE PATCH

Region	Theory	Simulated
B1	TM10=3.193GHz TM20=6.386GHz	TM10=2.310GHz TM20=6.155GHz
B2	TM10=3.154GHz TM20=6.309GHz	TM10=2.310GHz TM20=6.155GHz
B3	TM01=6.206GHz TM10=6.123GHz	TM01=6.155GHz TM10=6.155GHz

TABLE IV COMPARISON FOR H-SHAPE PATCH

Region	Theory	Simulated
C1	TM10=3.193GHz TM20=6.386GHz	TM10=vanished TM20=6.375GHz
C2	TM10=3.193GHz TM20=6.386GHz	TM10=vanished TM20=6.375GHz
C3	TM01=6.206GHz TM10=6.123GHz	TM01=5.685GHz TM10=5.685GHz

3.4 Conclusion

As per the above discussions and comparisons between the theoretical, simulated and measured results, it can definitely be concluded that the inabilities of multi-cavity model do not overshadow the fact that it is a great helping tool in getting a first hand knowledge of the frequencies that will be encountered physically in a slotted patch and helps in avoiding the rigorous hit and trial method for getting desired frequencies. The slight difference between the simulated and the tested results may occur because of adversities arising during fabrication of the antenna and soldering of the connector.

Thus one can come to a conclusion that the occurrence of multiple frequencies in a slotted patch is because of the presence of the multiple sub-sections each contributing to its own share of frequency as per its dimensions.

CHAPTER 4
DESIGN AND ANALYSIS OF A MINIATURIZED RECTANGULAR PATCH WITH L AND S SHAPED STRIPS FOR WLAN, WiMAX AND IMT APPLICATIONS

4.1 Introduction

A pioneering CPW-fed rectangular patch having L and S shaped meander strips has been propounded for WLAN, WiMAX and IMT applications. The antenna design has been simulated, fabricated as well as theoretically analyzed by transmission and cavity model for setting up a correlation between the frequencies obtained in all three cases, thus helping in anticipating the frequencies on paper. The proposed antenna resonates well below -10 dB covering the required band of 2.7/3.4/4.4 GHz IMT, 5.1 GHz WLAN and 3.4/5.2 GHz WiMAX standards.

After the advent of the Printed Circuit Board (PCB) technology, the microstrip patch antenna has proven to be a boon to the wireless industry and since then its popularity has been soaring high because of it being designer and user friendly in terms of its low profile, easy fabrication and embedment with Monolithic microwave integrated circuits, light weight and cost which is the ultimate desire of today's end users regarding their appliances. Despite being so much advantageous and a part of umpteen applications be it mobile phones, radio frequency identification (RFID), radio detection and ranging systems, television, aircrafts and spacecrafts etc, it carries a blot of being an antenna with narrow bandwidth, low gain and relatively larger size such that the classical patch antenna has to go through several manipulations in its designs before it can be employed for some application. Such amendments include stacking, etching slots of various shapes like U, C, L, S, usage of coplanar waveguide feed, electromagnetic band gap structures (EBG), cavity backing and lens covering etc. that aid in getting the desired bandwidth and gain. Further the fast growing wireless communication systems continuously desire for an antenna that incorporates the technologies like WLAN, WiMAX, Bluetooth, IMT etc. for which the regular patch antenna has to designed in a way that it alone caters to all these features. In order to deploy such a multifunctioning antenna in hand held devices, the utmost requirement is the small size of the antenna.

In this chapter, a classical rectangular patch antenna modulated such that the overall design is an amalgamation of L and S shaped meander strips being fed by CPW feed has been presented. The region responsible for particular technology has been studied theoretically by equating every strip to a single cavity whose length and width has the onus of giving a particular resonant mode thus making the entire structure multi-band. Also the simulated and fabricated results are matched with the theoretical results to understand the extent to which theory helps in estimating the frequencies.

4.2 Theoretical Considerations, Antenna Design & Fabrication

A 29×20 mm^2 compact antenna has been designed as shown in Figure-4.1 and Figure-4.2. The antenna has been fabricated on an 1.524 mm thick FR-4 substrate having 0.0024 loss tangent. The antenna has been fed by 50-Ω Coplanar Waveguide feed having 3.6 mm wide strip along with a pair of 0.4 mm wide gaps between the strip and CPW ground plane. At a low value of characteristic impedance like 50Ω, this CPW feeding mechanism being lossy results in lesser Q factor value, thus providing higher bandwidth as desired. The proposed antenna consists of the coalition of L and S shaped meander strips which together let the antenna resonate for Wireless Local Area Network (WLAN), Worldwide interoperability for Microwave access (WiMAX) and International Mobile Telecommunication (IMT) band applications.

In this structure, both the L and S shaped strips are controlling the occurrence of all the 2.7/3.4/4.4 IMT bands. The S-shaped strips are controlling the operation of 5.1 GHz WLAN and 5.2 GHz WiMAX and a few portion of S is responsible for 3.4 GHz WiMAX operation with a center frequency of 3.5 GHz. In order to realize this structure, Computer Simulation Technology (CST) microwave studio V’14 has been used and thus all the dimensions in mm have been optimized as shown in Figure-1 to get the desired frequency bands in a single structure. Further the regions responsible for particular resonances are analysed theoretically using the transmission line and cavity model which give an approximate insight and idea about the probable behaviour of every section of the design having a particular length and width. It is done by dividing the whole structure into fragments/subsections such that each sub-portion acts as a cavity in its own, thus resulting in multiple cavities in a single structure, each responsible for contributing for a particular resonance according to the parameters defined in Chapter-3.

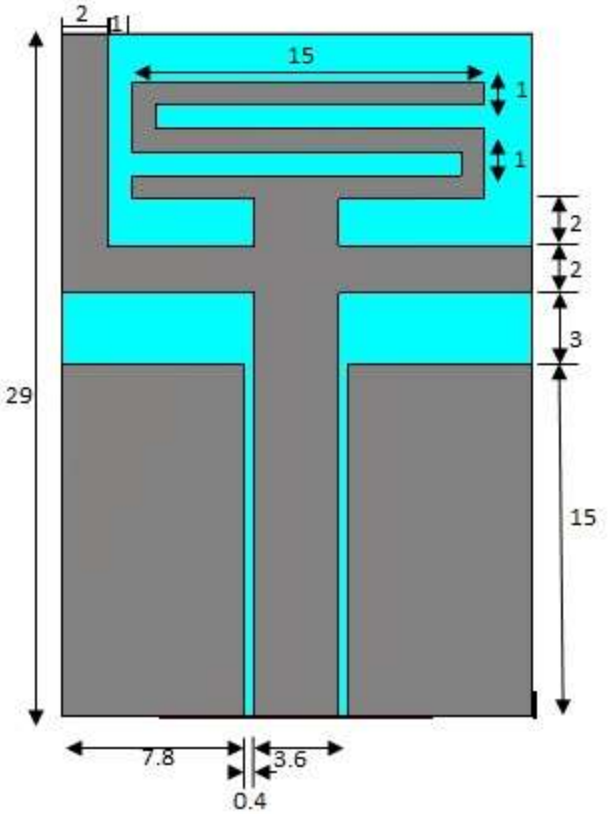


Figure 4.1: Geometry and Dimensions of Antenna Proposed

4.3 Simulated, Measured and Theoretical Results with Comparison & Discussions

In order to understand the behaviour of the proposed antenna design, the antenna has been theoretically studied, simulated, fabricated and then tested using Agilents Vector Network Analyzer (VNA) E 5071 C series. The final simulated results are shown in Figure-4.3. The figure shows the excitement of various resonant modes at 3.06 GHz, 3.6 GHz and an extremely wideband centered about 5 GHz which contribute in covering the frequency range for WLAN, WiMAX and IMT band applications.

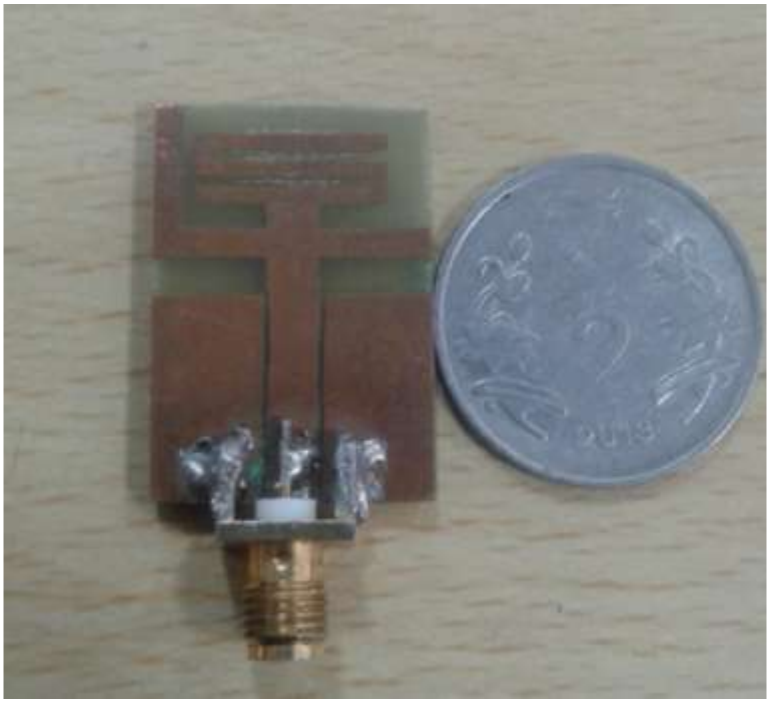


Figure 4.2: Photograph of the Antenna Design Proposed

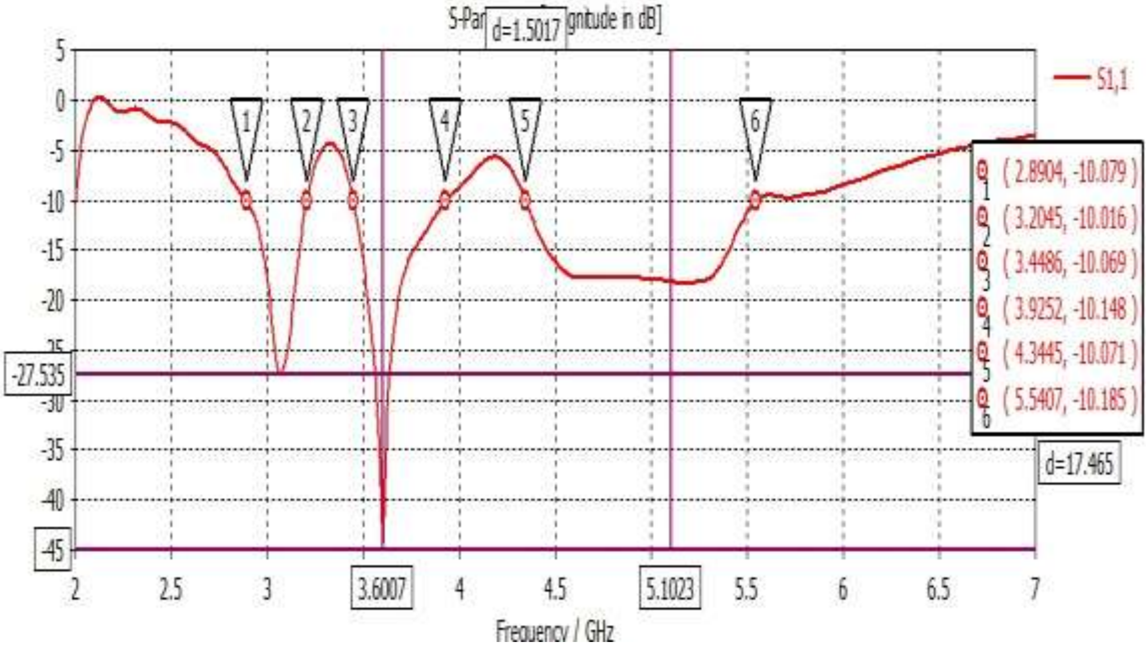


Figure 4.3: Simulated S_{11} Parameter Result

IMT band application include (2.8-3.2) GHz with 400 MHz bandwidth, (3.4-3.9) GHz, (4.4-4.9) GHz covering 500 MHz of the bandwidth with a promising return loss of -27.479 dB, -44.227 dB and an avergae return loss of -17 dB over the wideband respectively. The demand for WiMAX applications is catered by the (3.4-3.9) GHz and (5.2-5.5) GHz band covering a bandwidth of 500 MHz and 300 MHz respectively and (5.1-5.3) GHz band serves for WLAN application covering the required 200 MHz bandwidth. The resonant frequencies so obtained are analyzed using transmission line and cavity model as has been described by the equations (1) to (4). As per the theory, the regions mainly responsible for the resonance are shown in Figure-4.4. The yellow coloured L strip constitutes the first region of interest and the green coloured strips of S and the feed ground plane as per their dimensions together constitute the second region from which resonance is expected.

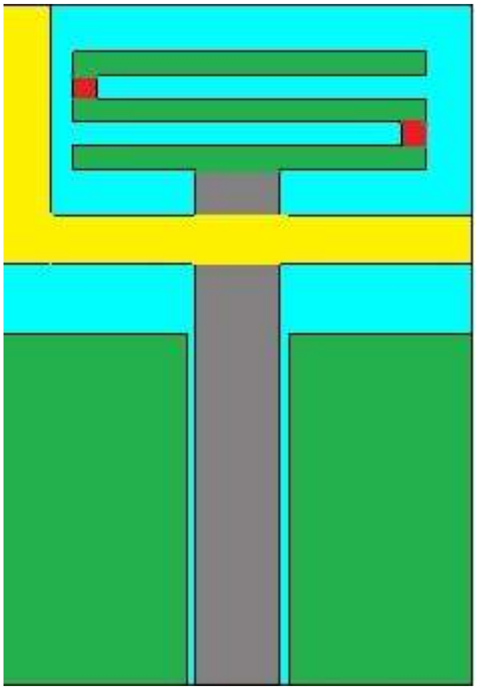


Figure 4.4: Figure Defining Regions

Now taking the first region into consideration, the length and width of L strip being 11×20mm^2 respectively such that $w_{sub} > L_{sub} > L_{sub}/2 > h$ causes TM01 mode to be dominant resulting in a frequency of 3.7 GHz theoretically. This theoretical frequency gets approximately justified by the presence of a resonance at 3.37 GHz as shown in the simulated S_{11} parameter results of Figure-4.5 when only L strip is made. Also the surface current distribution at this resonance does prove that the region mainly responsible for this resonance is the L shaped strip as can be justified via Figure-4.6(a). Also the coplanar waveguide feed ground plane being dimensionally equal to 15×15.6 mm^2 with $w_{sub} > L_{sub} > L_{sub}/2 > h$ has TM01 as its dominant mode and according to this it should provide a resonance near to 4.8 GHz theoretically. The resonance at 5.1 GHz and its surface current distribution in Figure-4.6(b) somehow give an indication that the region responsible for this resonance is the ground plane.

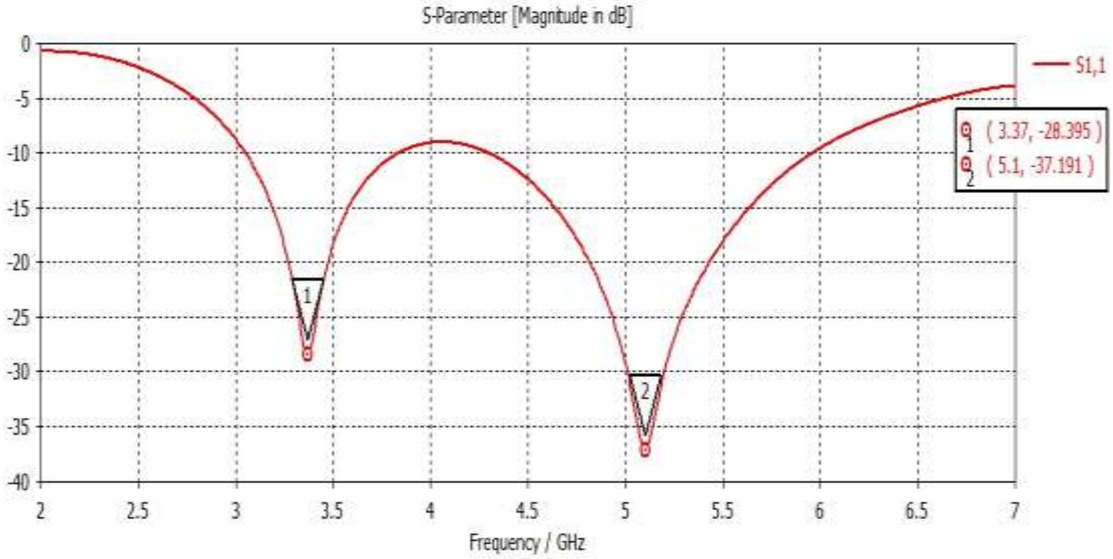
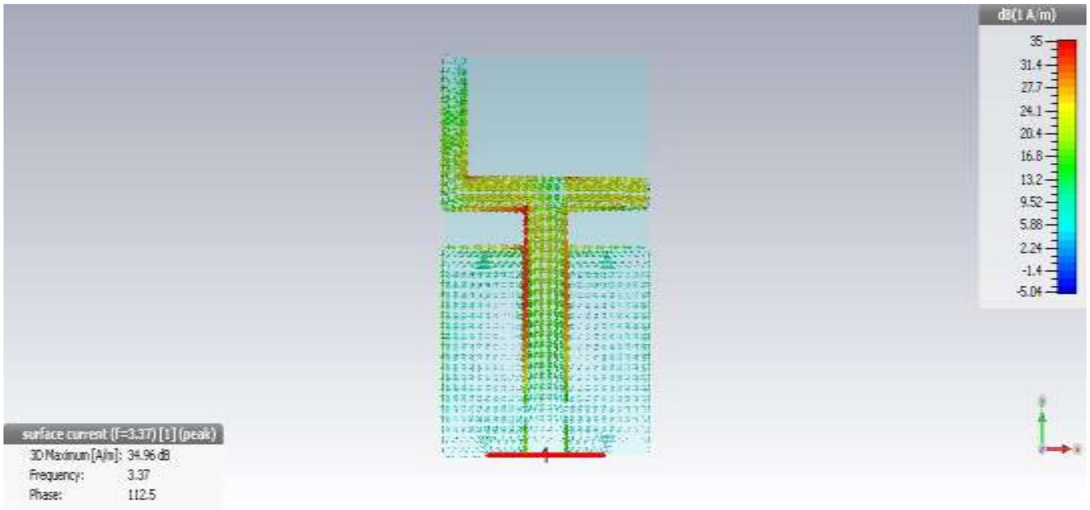
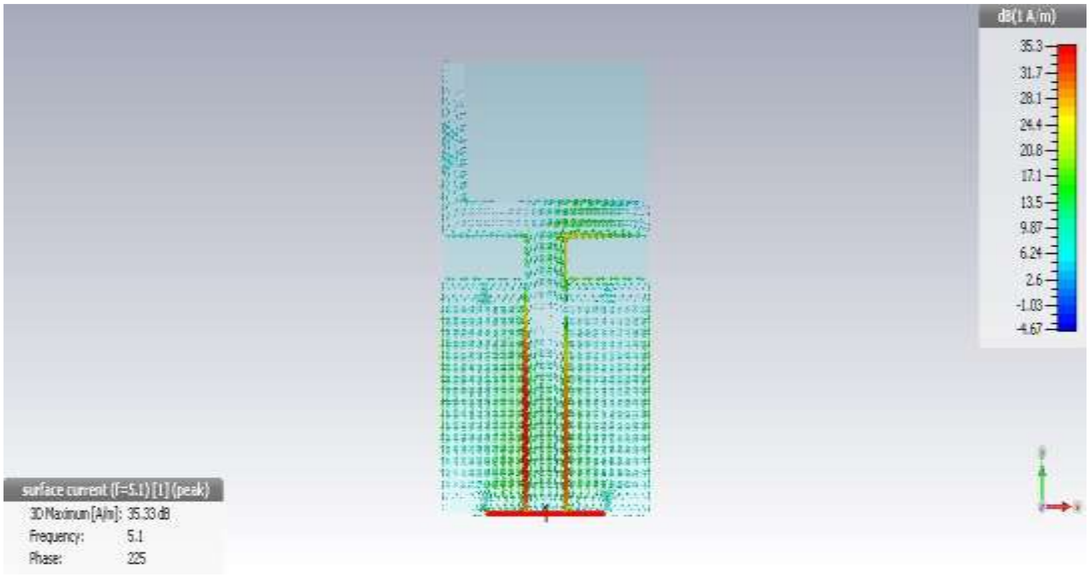


Figure 4.5: Simulated S_{11}-Parameter for Partial Antenna Design Consisting of only L Strip and Ground Plane



(a) Current Distribution at 3.37 GHz

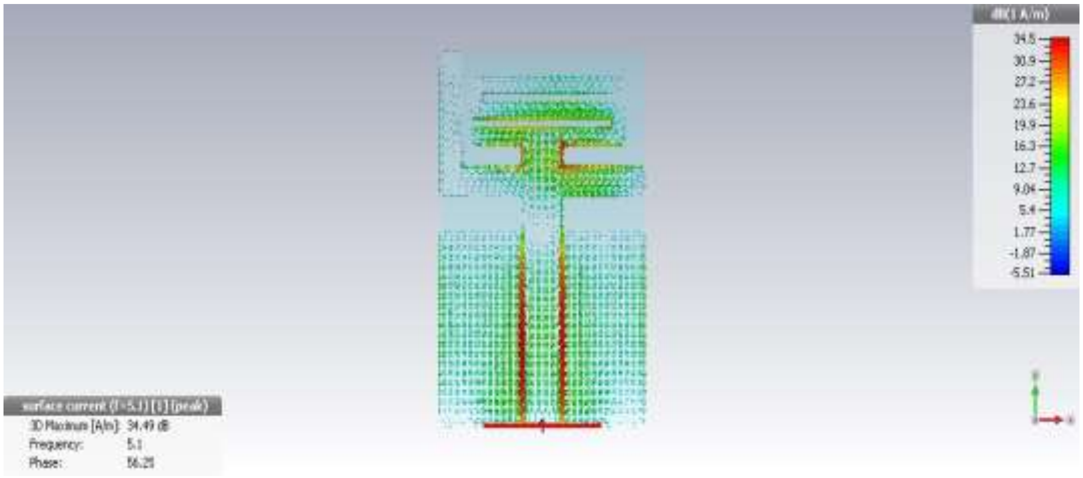


(b) Current Distribution at 5.1 GHz

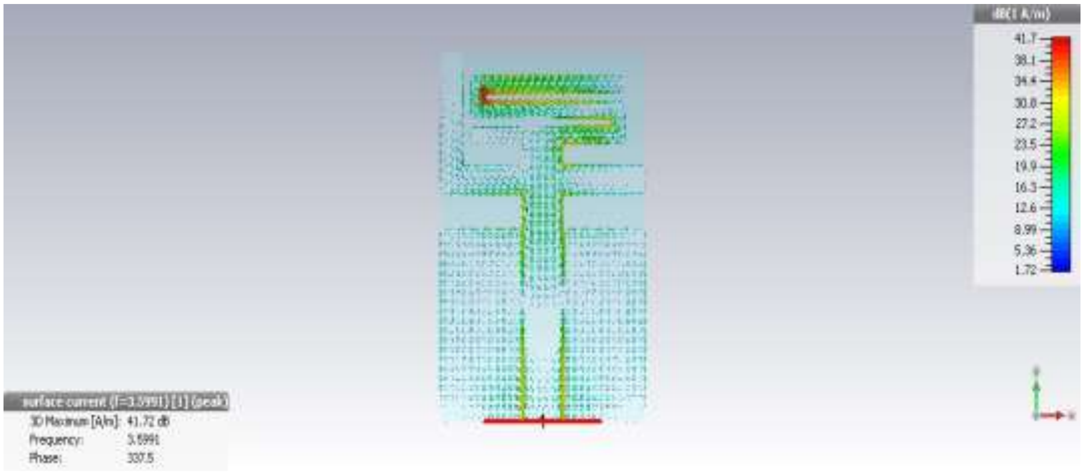
Figure 4.6: Current Distributions with L-Strip And Ground Plane only

The final structure is formed upon the introduction of S-shaped meander strip, along with the already present L-shaped strip, each arm of which has equal dimensioned length and width of 1×15 mm^2 with $w_{sub} > w_{sub}/2 > w_{sub} > h$ thus having TM01 mode as the dominant one. As per its dimensions the single arm of S-shaped strip should result in a resonance of about 5.6 GHz theoretically. Also during simulation it is observed that when all the arms of S-shaped meander are being constructed the bandwidth about 5.1 GHz central frequency starts increasing owing to an increase in the electrical length of the region responsible for this resonance. Hence as per the theory, it can be said that all the arms of S-shaped meander should collectively be responsible for giving a wideband around 5 GHz approximately, which is supported by the presence of the wideband generated around the central frequency of 5.1 GHz, which had occured previously because of the ground plane.

But practically, this antenna structure gives a very strong resonance at 3.6 GHz as can be seen in Figure-4.3 about which the theory does not point about. Also as the S-shaped meander is formed, the resonance of 3.37 GHz due to the L-shaped strip gets shifted towards left to a value of 3.06 GHz in the final structure which is due to the increase in the inductance value about which the multi cavity model is unable to predict. As per the simulation results only the lower portion of the S-shaped meander strip and the ground plane are responsible for contributing to the wideband occurring around the 5.1 GHz frequency and the upper portion of the S-shaped strip is actually contributing for the 3.5 GHz resonance. This has been shown in Figure-4.7 (a)&(b).



(a) Current Distribution at 5.1 GHz.



(b) Current Distribution at 3.5 GHz.

Figure 4.7: Current Distributions for given Frequencies

Hence an inference can be drawn here that with the help of transmission line and multi-cavity model, one can easily get a rough estimation of the frequencies that will result from the sub-sections of the antenna thus helping in the rapid optimization of the parameters for getting desired frequency bands. Figure-4.8 shows the comparison between the theoretical, simulated and the measured results. The measured results do support the simulated results and are in good favour of them. The minor deviations between the simulated and the measured results may occur due to the snags that arise during fabrication and soldering processes.

Also looking at the theoretical results that have been drawn roughly by calculating S_{11} parameter values at required frequencies, one can say that, prediction of 65-70% of the behaviour of the antenna is possible on paper. The Figure-4.9(a) shows the simulated polar plot view of the S_{11} parameter with the respective markings depicting the bands over which the antenna is working.

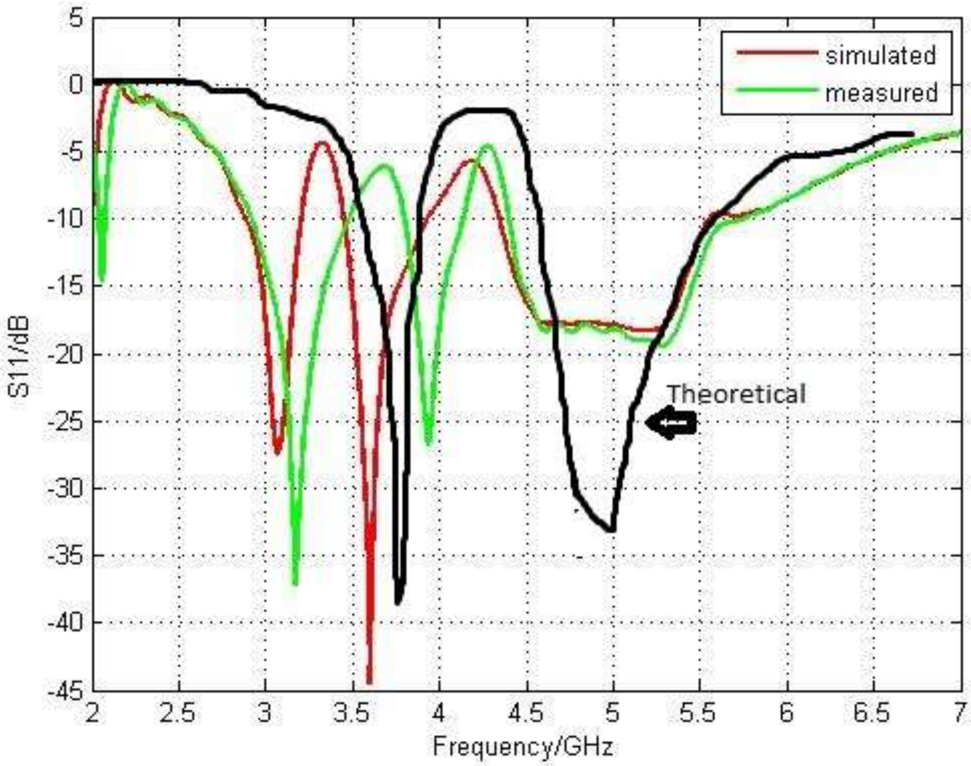
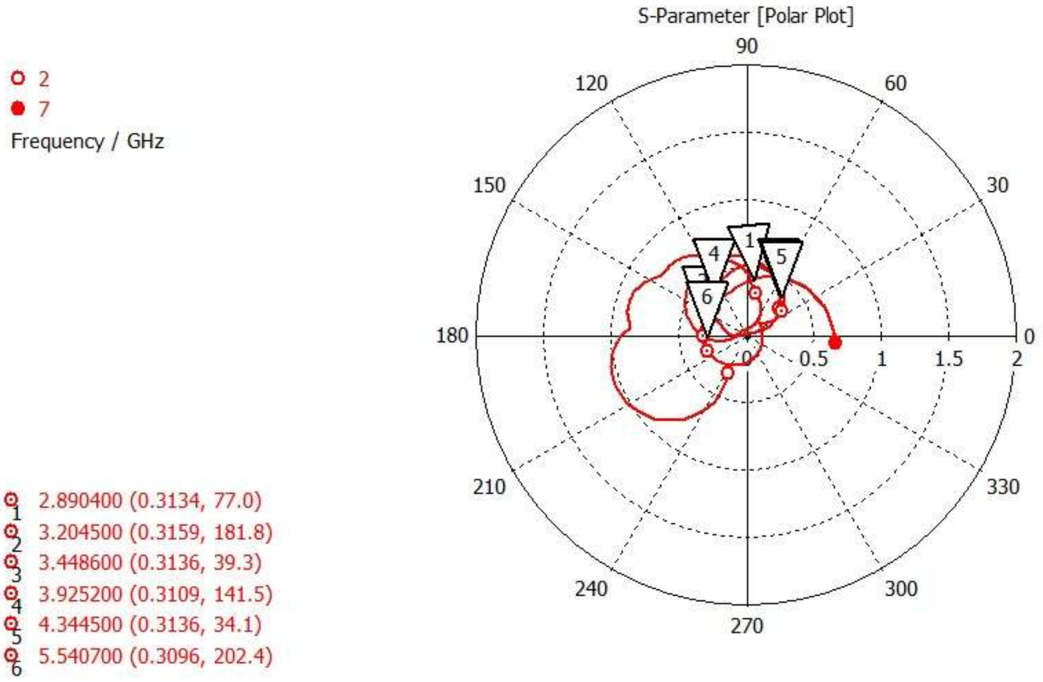
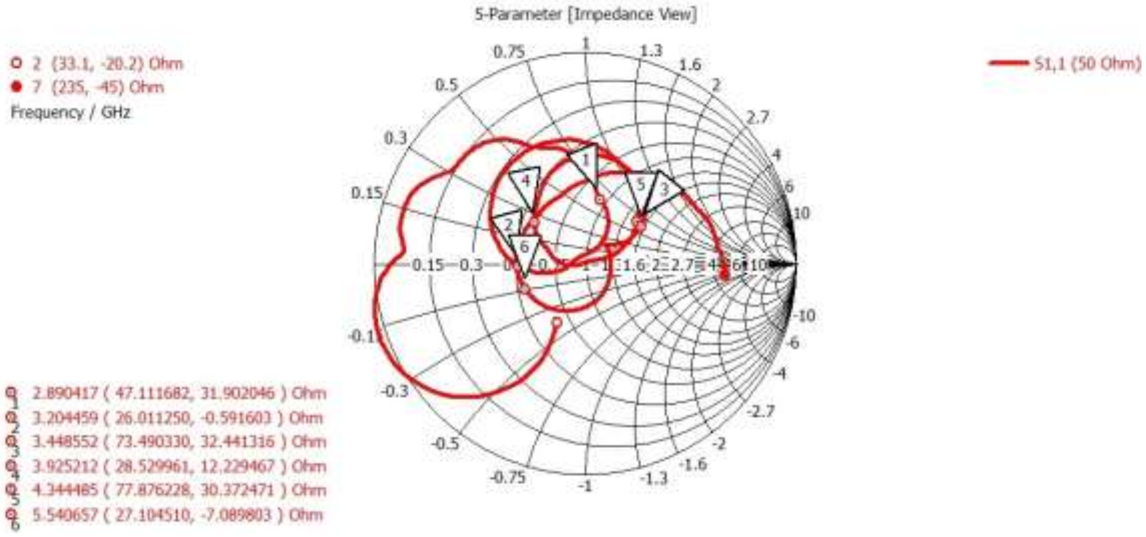


Figure 4.8: Comparison of simulated, measured and theoretical results



(a) Simulated S_{11} Parameter Polar Plot View



(b) Smith Chart showing perfect 50-ohm matching

Figure 4.9: Polar Plot and Smith Chart

Figure-4.9(b) shows the simulated smith chart of the patch antenna showing a perfect impedance match of 50 **Ω**. The stiff and tight resonant loop near to the Smith Chart's center indicates large improvement in the antenna's impedance bandwidth. Figure-4.10 shows the VSWR of the antenna proposed at 3.06, 3.6 and 5.1 GHz. VSWR value should ideally be one to show perfect matching. In our case the values at the corresponding frequencies are 1.0881, 1.012 and 1.2807 with the impedance transformation ratios as 1:1.0881, 1:1.012 and 1:1.2807 indicating a very good match to 50-ohm line thus allowing maximum transfer of the power.

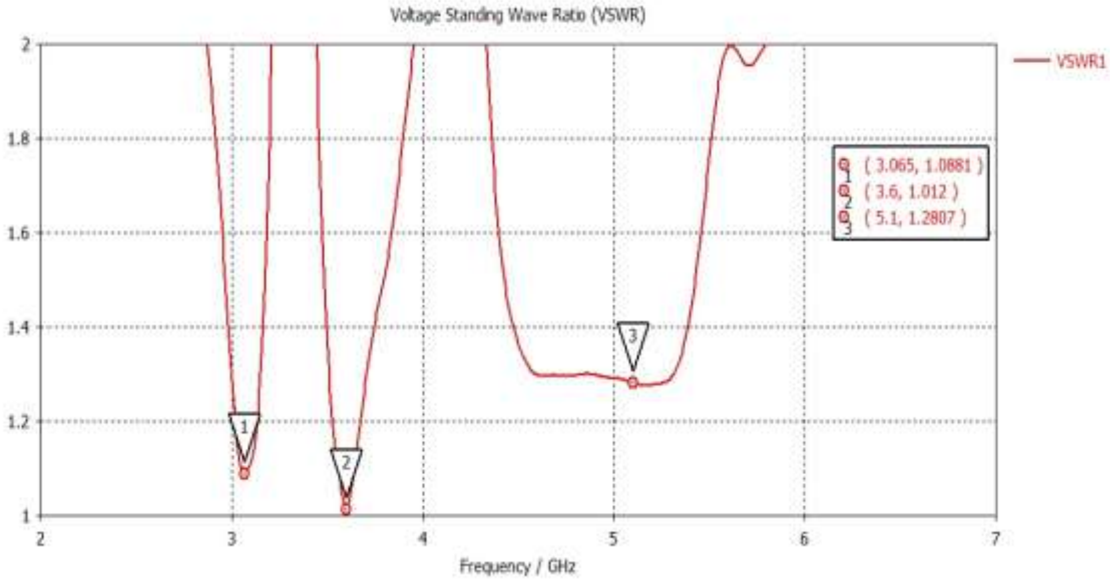
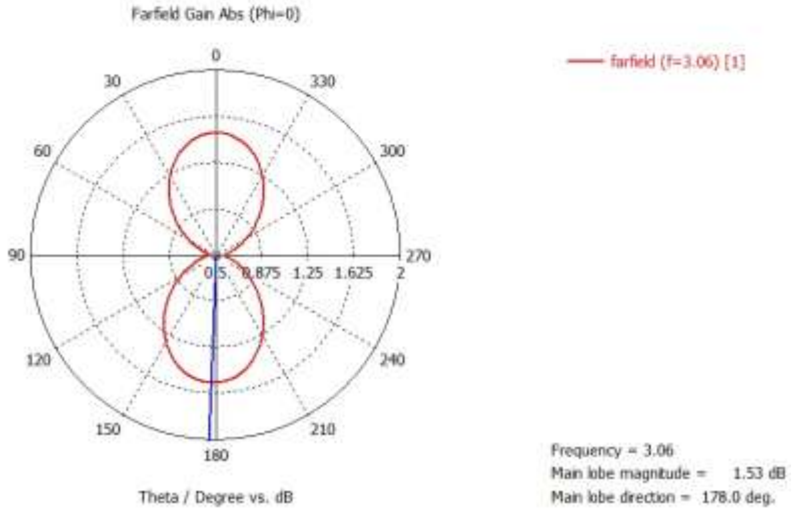


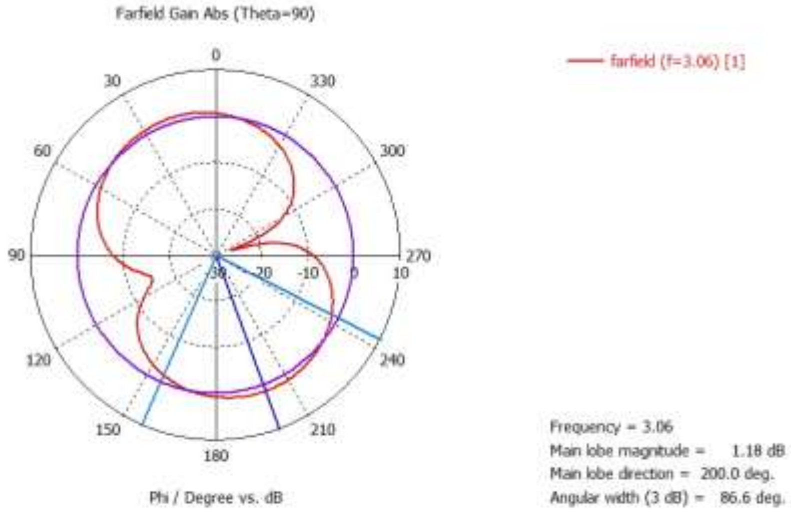
Figure 4.10: VSWR of the proposed antenna at 3.06, 3.6 and 5.1 GHz

In Figure-4.11, 4.12 & 4.13, the E (elevation) and H (azimuthal) plane radiation pattern of the antenna, defining its radiation characteristics as a function of space, have been shown at the resonating frequencies of 3.06 GHz, 3.6 GHz and at 5.1 GHz about which the wideband starts forming.

A bidirectional elevation radiation pattern is observed at 3.06 GHz, 3.6 GHz and 5.1 GHz with a gain of 2.13 dBi, 2.32 dBi and 3.07 dBi respectively. Also nearly omnidirectional azimuthal radiation pattern has been achieved. The graph for the variation of gain (dBi) according to the frequencies has been shown in Figure-4.13 in which the gain for the complete (4.3-5.5) GHz band can also be visualized.

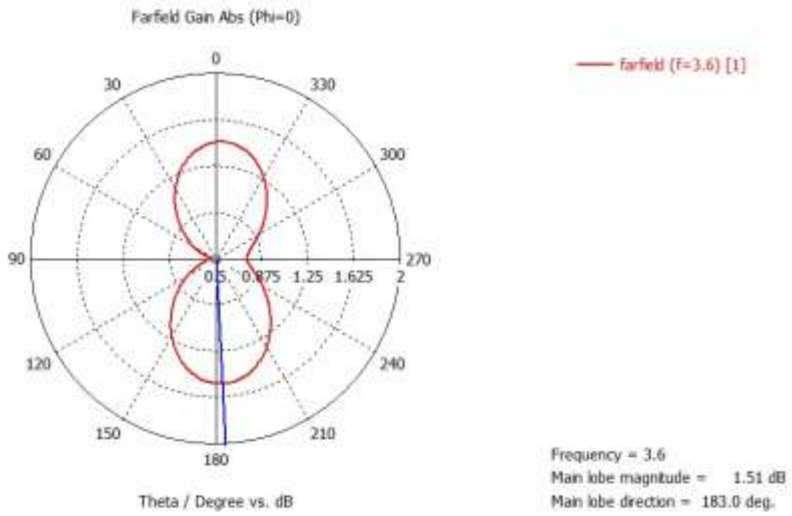


(a) E-plane Radiation Pattern

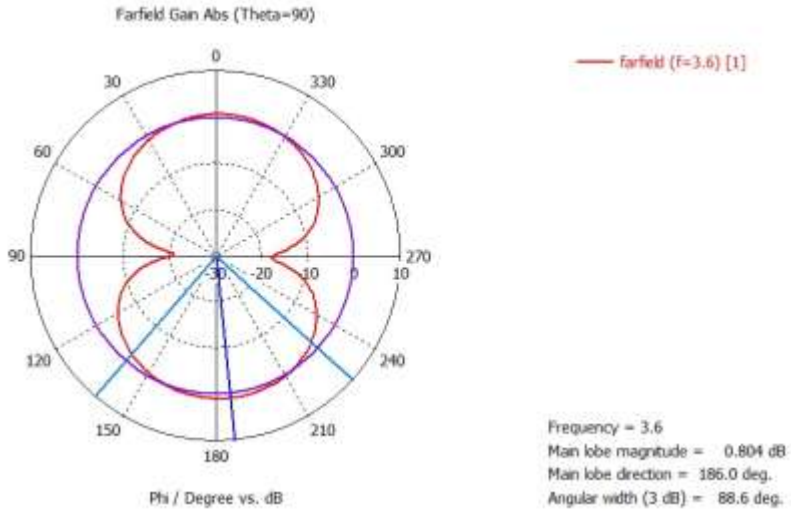


(b) H-plane Radiation Pattern

Figure 4.11: Elevation and Azimuthal Radiation Pattern at 3.06 GHz

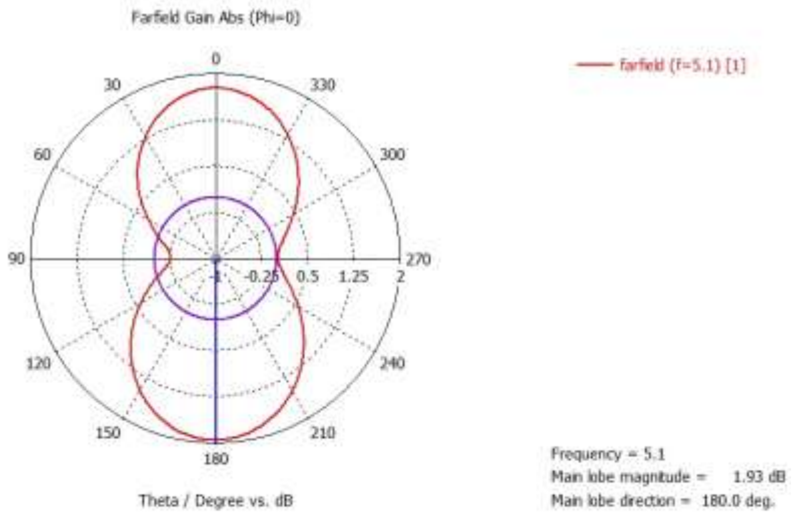


(a) E-plane Radiation Pattern

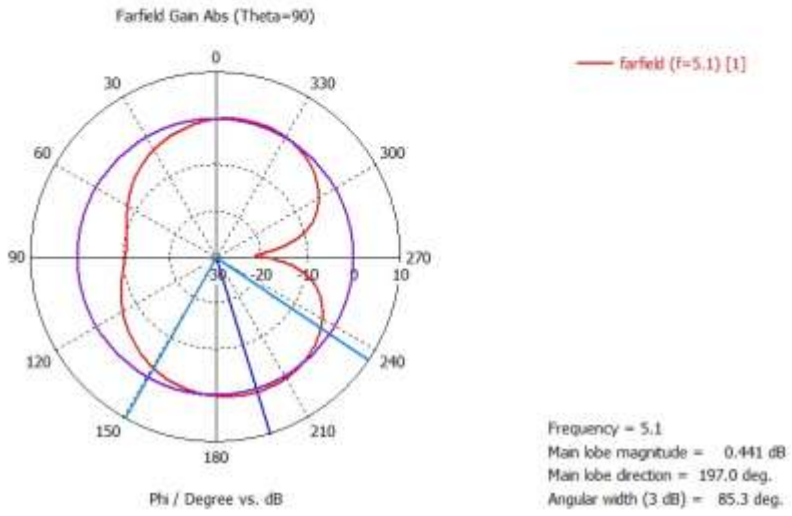


(b) H-plane Radiation Pattern

Figure 4.12: Elevation and Azimuthal Radiation Pattern at 3.6 GHz



(a) E-plane radiation Pattern



(b) H-plane Radiation Pattern

Figure 4.13: Elevation and Azimuthal Radiation Pattern at 5.1 GHz

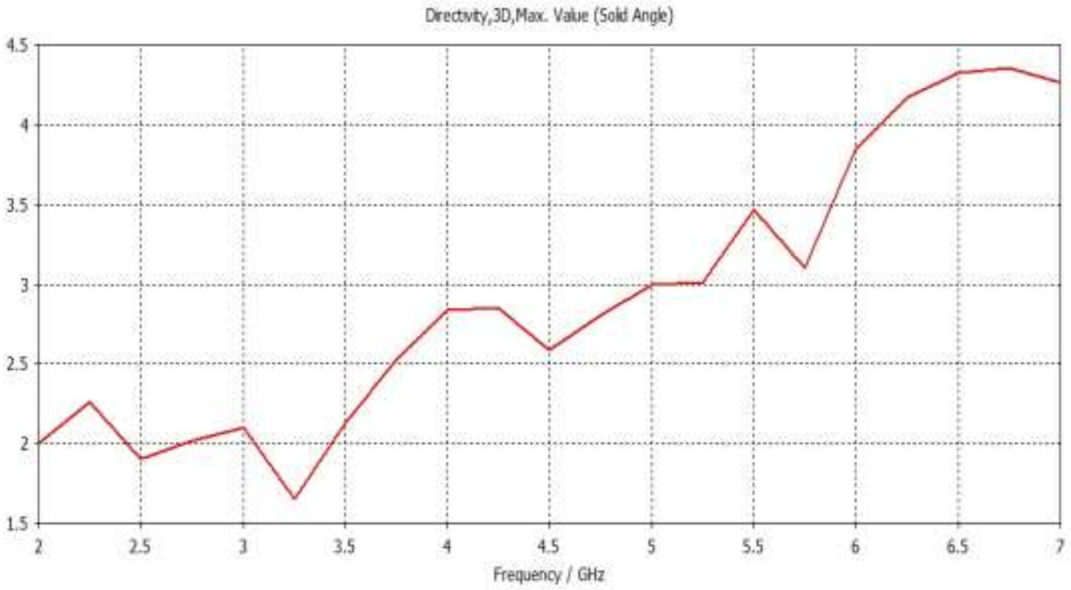


Figure 4.14: Gain (dBi) vs Frequency curve

4.4 Conclusion

A compact microstrip patch antenna with L and S-shaped meander strips has been simulated, theoretically analyzed, fabricated and tested for proving the sanctity of the results. Coplanar waveguide feed is used to exploit its ability of providing wide bandwidths. The proposed antenna has a very wide scope of being employed for the purpose of WLAN, WiMAX and IMT band applications offering very good impedance bandwidths (at VSWR<2) of about 400 MHz and 500 MHz for different IMT bands, 500 MHz and 300 MHz for WiMAX application and the required 200 MHz for WLAN band applications. Also a good approximation for the behaviour of the antenna is observed by theoretically analyzing the antenna with the help of transmission line and multi-cavity model. It is observed that the multi-resonant behaviour of the antenna is because of the different sub-sections of the design acting as a cavity in their own thus giving a resonance as per their effective length and width. The small size of the antenna makes it a favourable candidate for its integration in the hand-held devices. Some further manipulations can be done to increase the gain of the antenna at the wireless applications specified.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The work done in the thesis was motivated by the evergrowing demand for small, inexpensive and multifunctional antennas in the wireless communication industry. The survey done on the literature available identified umpteen novel, compact, large bandwidth and multifunctional microstrip patch antennas for various wireless applications. Achieving these features has been the core interest of the researchers. The traditional rectangular patch antenna is modified by number of ways in order to make them serviceable for consumer applications. Intensive parametric study is conducted to obtain desired frequency bands. As was identified during the survey, that cutting slots into a regular rectangular patch makes the antenna to be resonant at multiple frequencies. This observation became the motivation to identify the reason behind this multi resonant behaviour of a rectangular patch antenna which would somehow help in faster optimization of the parameters. CST microwave studio V'14 was used in the thesis to achieve the goals of performing the theoretical analysis of slotted patch antenna and designing of a compact, multi-frequency, wideband microstrip patch antenna. Thus looking at the results and the observations made following points can be concluded:

- Looking at the results of I, inverted T and H-shape slotted patch antennas, an inference can now be easily drawn that a microstrip patch antenna loaded with slots is nothing but multiple cavities; where each cavity as per its own effective dimensions produce a resonant frequency. Therefore, the presence of multiple cavities in a rectangular patch lets it resonate at multiple frequencies according to the dimensions of each cavity. This conclusion helps in estimating the frequencies that may result after loading a rectangular patch with the slots of given length and width. If not upto the mark, atleast one can reach near to the actual response.

- No doubt the transmission line and cavity models are approximate ones, but still one can easily get to know how the slotted patch antenna will be behaving after it is loaded with slots of particular length and width.

- Also the aim of designing a compact, large bandwidth and multifunctional antenna has been realized. CPW-fed rectangular patch having L and S shaped meander strips has been proposed for WLAN, WiMAX and IMT band applications. The proposed antenna resonates well below -10 dB covering the required band of 2.7/3.4/4.4 GHz IMT, 5.1 GHz WLAN and 3.4/5.2 GHz WiMAX standards. High bandwidth and reasonable gains at the resonating frequencies have been achieved. A good theoretical approximation of the design has been done which is somehow comparable to simulated and measured results.

5.2 Future Scope

Perfection is an illusion and hence there is always room for improvement. Therefore the research work presented in the thesis can be extended further in the following ways:

- Advanced models like full-wave analysis can be used as a tool to analyse the patch antenna's behaviour theoretically which may help in getting more accurate results.
- Further optimization of the parameters of the antenna discussed in chapter 4 can be done to make it smaller in size such that it can be incorporated in the least possible space in the devices.
- The design presented for WLAN, WiMAX and IMT applications, can be further manipulated to make the antenna capable of covering the remaining bands of WLAN technology.
- Scope also lies in getting better gain values at the resonating frequencies like by loading the top of the patch with a superstrate which may improve the radiation efficiency. Defected Ground Structure technique can also be implemented in the design to get further enhanced bandwidths.

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LIST OF PUBLICATIONS

1. Asmita, Jaswinder Kaur and Rajesh Khanna, “ Approximation of Multi Resonant behaviour of slotted patch antenna via Multi Cavity Model.” Communicated in *Microwave and Optical Technology Letters.*

2. Asmita, Jaswinder Kaur and Rajesh Khanna, “Design and Analysis of a miniaturized rectangular patch with L and S shaped strips for WLAN, WiMAX and IMT applications.” Communicated in *IETE Journal of Research.*

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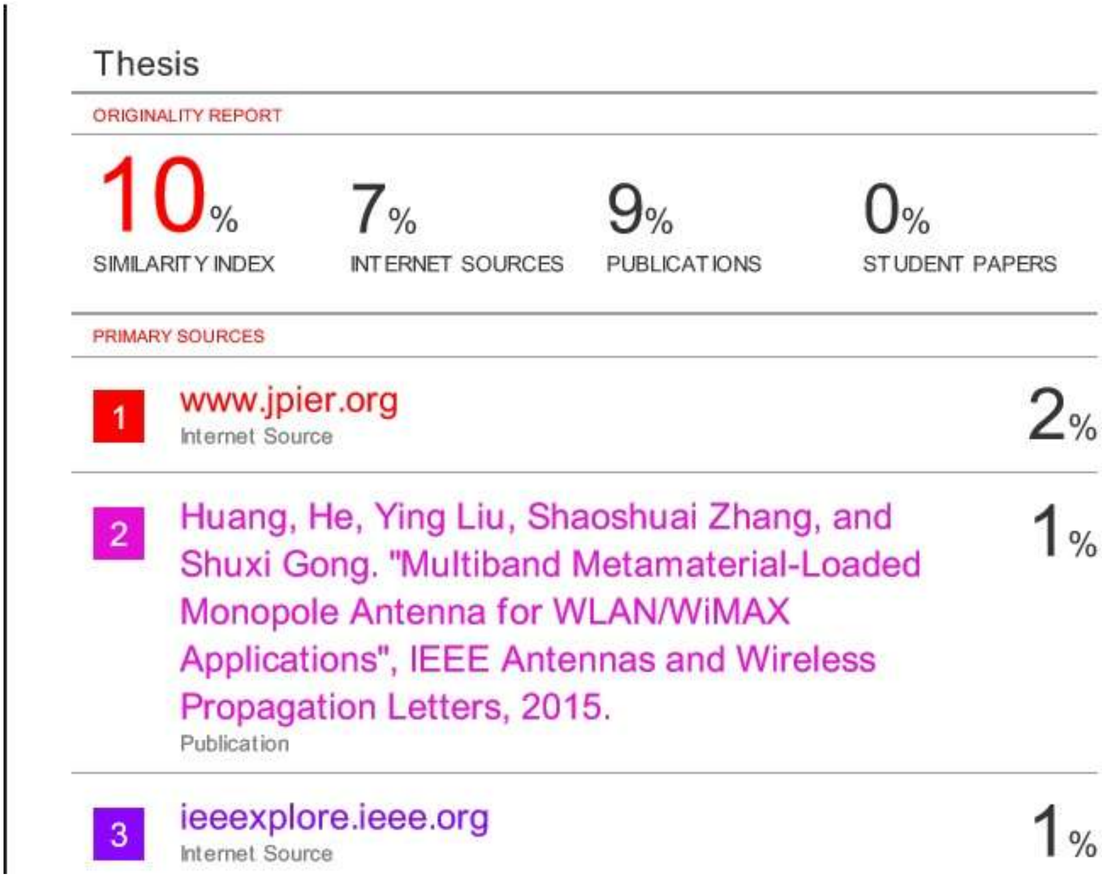

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