

NOTCH RECONFIGURABLE UWB ANTENNA DESIGN

A Thesis Submitted in Fulfillment of the Requirement for the Award of the Degree of

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Submitted By

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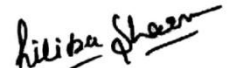
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JULY, 2018

DECLARATION


I, Ritika Sharma hereby declare that the work presented in this thesis entitled “**Notch Reconfigurable UWB Antenna Design**” in fulfillment of the requirement for the award of degree of Master of Engineering submitted at Electronics and Communication Engineering department, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala is an authentic record of work carried out under supervision of Dr. Rajesh Khanna (Professor, ECED, Thapar Institute of Engineering & Technology) from January 2017 to July 2018. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

Date: 11th July, 2018


Ritika Sharma

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

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ABSTRACT

The goal of this thesis is to first design a UWB circular antenna with single and dual notch band characteristics. Second goal of the research work is to design frequency reconfigurable antenna and understand the importance of multifunctional antennas due to the uplifting demand of high transmission rate and advance wireless communication. Reconfigurable antenna is designed by combining filters and antenna which are called filtennas. In this thesis we have designed a circular patch UWB antenna and further modified this antenna by placing two symmetrical resonators E and C shaped beside feedline to attain band notch characteristics. This technique is placing parasitic elements near the radiating patch for achieving band notch characteristics. After obtaining a notch band UWB antenna, a frequency reconfigurable antenna is designed. Reconfigurability is achieved by employing RF switch in correct location which connects two parasitic elements and reconfigures one shape into another that is reconfigures E shape to C shape or vice-versa. One single frequency reconfigurable antenna has two antenna characteristics. One antenna that is configured has capability to reject interferences from WLAN, WiMAX and C band spectrum. Second antenna is reconfigured when resonator shape changes to E shape from C shape and it has capability to reject interferences from WLAN, WiMAX, C band spectrum and X band satellite communication. The simulated and measured results have good agreement and measured radiation pattern represent that proposed antenna has omnidirectional characteristics in the H plane. Gain varies between 2 to 5.5 dB at different operating frequencies and is good for practical application. Practical applications require many services which reconfigurable antennas can generate and it can easily be integrated in portable devices. The proposed frequency reconfigurable antenna is simulated using CST Studio Suite Software.

TABLE OF CONTENT

Sr. No	Name of the Chapters	Page No
	<i>Declaration</i>	i
	<i>Acknowledgement</i>	ii
	<i>Abstract</i>	iii
	<i>Table of contents</i>	iv
	<i>List of tables</i>	vi
	<i>List of figures</i>	vii-ix
	<i>List of Abbreviations</i>	x-xi
<i>Chapter 1</i>	Introduction	1-4
	1.1 Background	1
	1.2 Motivation	3
	1.3 Objective of thesis	4
	1.4 Outline of thesis	4
<i>Chapter 2</i>	Literature Survey	6-14
	2.1 Introduction	6
	2.2 Summarized research papers	6-14
<i>Chapter 3</i>	Analysis of 'E' shaped structure	15-25
	3.1 Need of filter properties in UWB antennas	15
	3.2 Filter implementation	15-17
	3.3 Circuit analysis of various resonating structures	17-21
	3.3.1 Equivalent circuit of microstrip line	17-18
	3.3.2 Equivalent circuits typical discontinuities	18-21
	3.4 Circuit analysis of 'E' shaped filter structure	21-25
	3.4.1 Equivalent circuit and design equations of filter structure	22-25
<i>Chapter 4</i>	A Notch reconfigurable UWB antenna design	26-38

4.1	Introduction	26
4.2	UWB circular patch antenna design	26-29
4.3	UWB notch antenna design	29-30
4.4	Parametric study	31-34
4.4.1	Parametric study of length L1 of the E shaped resonator	31
4.4.2	Parametric study of length L2 of the E shaped resonator	31
4.4.3	Parametric study of length L3 of the E shaped resonator	32
4.4.4	Parametric study of length L4 of the E shaped resonator	33
4.4.5	Parametric study of length L5 of the E shaped resonator	33
4.4.6	Parametric study of length L6 of the E shaped resonator	34
4.4.7	Parametric study of length W of the E shaped resonator	34
4.5	Reconfigurable notch UWB antenna design	34-38
<i>Chapter 5</i>	Fabrication and testing	39-46
5.1	Introduction	39
5.2	Results and discussion	40-46
<i>Chapter 6</i>	Conclusion	47
	<i>References</i>	48-52
	<i>List of Publications</i>	53
	<i>Appendix</i>	

LISTS OF TABLES

Table 1.1	Frequency bands description	2
Table 3.1	Parametric values of equivalent circuit model of proposed antenna	25
Table 4.1	Dimensions of resonating structure	30
Table 4.2	Different RF switching states and resonators shape	36
Table 5.1	Antenna operation for different states of switches	40

LIST OF FIGURES

Figure 1.1	Spectrum comparison of Ultra Wide Band and narrowband signals	3
Figure 3.1(a)	Transmission line representation its equivalent circuit	17
Figure 3.1(b)	Transmission line equivalent circuit	17
Figure 3.2	Equivalent circuit of gap coupled microstrip line and open circuited resonator	18
Figure 3.3	Frequent discontinuities in any circuits	19
Figure 3.4(a)	Bent structure	19
Figure 3.4(b)	Equivalent circuit of bent structure	19
Figure 3.5(a)	Open end structure	20
Figure 3.5(b)	Equivalent circuit of open end structure	20
Figure 3.6(a)	Gap structure	20
Figure 3.6(b)	Equivalent circuit of gap structure	20
Figure 3.7(a)	Structure representing variation in width	20
Figure 3.7(b)	Equivalent circuit of variation in width structure	20
Figure 3.8(a)	T junction structure	21
Figure 3.8(b)	Equivalent circuit of T junction structure	21
Figure 3.9	‘E’ shaped filter structure.	21
Figure 3.10	E shaped structures coupled with feedline of radiating patch.	22
Figure 3.11	Equivalent structure of microstrip feedline	24
Figure 3.12	Equivalent circuit model of designed antenna	25
Figure 3.13	Equivalent circuit of filter section I	25
Figure 4.1	Circular UWB antenna design	27
Figure 4.2	Equivalent circuit of circular patch	28

Figure 4.3	Simulated return loss curve of Circular UWB antenna design	28
Figure 4.4	Parametric study of ground's length L_g	29
Figure 4.5	UWB notch antenna	29
Figure 4.6	Labeled view of E shaped resonator	30
Figure 4.7	Simulated return loss with variations in length L_1 of resonator structure	31
Figure 4.8	Simulated return loss with variations in length L_2 of resonator structure	32
Figure 4.9	Simulated return loss with variations in length L_3 of resonator structure	32
Figure 4.10	Simulated return loss with variations in length L_4 of resonator structure	33
Figure 4.11	Simulated return loss with variations in length L_5 of resonator structure	33
Figure 4.12	Simulated return loss with variations in length L_6 of resonator structure	34
Figure 4.13	Simulated return loss with variations in width W of resonator structure	34
Figure 4.14	Front view of the reconfigurable UWB antenna	35
Figure 4.15	Closure view of E shaped and C shaped resonator	35
Figure 4.16	Simulated return loss when both switches are 'ON'	37
Figure 4.17	Simulated return loss when one switch is 'ON' and other is 'OFF'	37
Figure 4.18	Simulated return loss when both switches are 'OFF'	38
Figure 5.1	Picture of fabricated antenna	39
Figure 5.2	Picture of back side of fabricated antenna	39
Figure 5.3	Simulated and measured results of frequency reconfigurable antenna when RF switches are OFF.	41
Figure 5.4	Simulated and measured results of frequency reconfigurable antenna when one of the RF switches is ON and other is OFF	41
Figure 5.5	Simulated and measured results of frequency reconfigurable antenna when both RF switches are ON	42
Figure 5.6	Simulated surface current distributions for proposed reconfigurable C shaped antenna at the notch frequency 5.1 GHz	43

Figure 5.7	Simulated surface current distributions for proposed reconfigurable E shaped antenna at the notch frequencies 5.1 and 8.55	43
Figure 5.8	Simulated maximum gain comparison of single band notch and dual band notch when switches are off and on respectively	44
Figure 5.9	Comparison of simulated VSWR when switches are on and off	44
Figure 5.10	Measured and simulated results of radiation pattern of E, H plane when switches are OFF at frequencies 3.2 GHz, 7.3 GHz and 9.8 GHz	45
Figure 5.11	Measured and simulated results of radiation pattern of E, H plane when switches are ON at frequencies 5.1 GHz, 6.8 GHz and 8.4 GHz	46

LIST OF ABBREVIATIONS

FCC	Federal Communication Commission
UWB	Ultra Wideband
WiMAX	World Interoperability for Microwave Access
WLAN	Wireless Local Area Network
RF	Radio Frequency
GPS	Global Positioning System
Wi-Fi	Wireless Fidelity
NASA	National Aeronautics and Space Administration
MSS	Mobile Satellite Service
FSS	Fixed Satellite Service
BSS	Base Station Subsystem
EBG	Electromagnetic Band-Gap
MEMS	Micro-Electro-Mechanical Systems
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio
SRSSLR	Square Ring Short Stop Loaded Resonator
RFID	Radio Frequency Identification
DGS	Defected Ground Structure
SRR	Split Ring Resonator
MSA	Microstrip Antenna
CSRR	Circular Split Ring Resonator
CPW	Coplanar Waveguide
HIPERLAN	High Performance Radio Local Area Network
SRR	Split Ring Resonator
CRR	Closed Ring Resonator
MMR	Multi Mode Resonator
SIR	Stepped Impedance Resonator

WBAN	Wireless Body Area Network
EBG	Electromagnetic Band Gap
VNA	Vector Network Analyzer
CST	Computer Simulation Technology
FR4	Flame Retardant 4
SPST	Single Pole Single Throw
SPDT	Single Pole Double Throw
SP4T	Single Pole Four Throw

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

An antenna is a special type of transducer that converts alternating current into radio frequency signals or vice-versa [1]. There are different types of antennas; the most popular antennas for wireless communication system are microwave antennas, travelling wave antennas, log periodic antennas, wire antennas and reflector antennas. Microstrip antennas fall under the category of microwave antennas and are widely used due to their compact size, light weight and easy to fabricate [2]. Microstrip antennas can easily be placed on the surface of airplanes, missiles, mobile phones and many objects for reliable communication [3].

The rapid increase of wireless systems have created bandwidth shortage, to overcome the shortage in the year 2002 FCC [4] authorized the unlicensed use of UWB in the range 3.1 GHz to 10.6 GHz. Earlier this technology was exploited by military and government organizations. Presently, there is uplifted enthusiasm for UWB applications for remote correspondence frameworks because of its great highlights, for example, high information transmission rate, low spectral power density and minimal cost. Difference between ordinary radio transmissions and UWB is that traditional frameworks transmit data by fluctuating the power level, frequency, or phase of a sinusoidal wave whereas UWB transmissions transmit data by generating radio energy at particular time gaps that covers large bandwidth and this enables time modulation. Numerous antennas have been intended for UWB applications utilizing different procedures. UWB technology is perfect for indoor application due to its low power spectral density which does not interfere with other narrowband system in the same space. For low data rate applications like computer peripherals this technology can be used for wireless connection. To utilize the available bandwidth and provide high internet access UWB is the best option for low power devices or handheld devices. Short pulse UWB technology provides precision in tracking objects or humans in critical conditions [52].

Many antennas have been designed for UWB applications using various techniques. The UWB works in the range from 3.1 GHz – 10.6 GHz, interferences from many existing narrow band is ensured as shown in the figure 1.1. Narrow band systems are WiMAX, WLAN, C and X band satellite communication system shown in the table 1.1.

Table 1.1 Frequency bands description.

Band	Frequency Range	Applications
L	1 to 2 GHz	GPS, Mobile satellite services, radio, telecommunication and aircraft surveillance
S	2 to 4 GHz	Bluetooth, Wi-Fi, NASA, MSS, deep space research
C	4 to 8 GHz	Wi-MAX, Fixed satellite service (FSS)
X	8 to 12 GHz	Radar, Satellite communication, FSS Military
Ku	12 to 18 GHz	Broadcast satellite services (BSS)
K	18 to 26 GHz	Radar and satellite communication
Ka	26 to 40 GHz	FSS, Future for space communication

UWB spectrum has the ability to work in the noise floor which lets this spectrum share with other co-existing traditional wireless systems [5]. To avert the interferences from these narrow bands UWB antenna need to be modified. Band notching techniques are used to filter out interfering signals [45]. Band notching can be done by various techniques like employing parasitic elements [34] along the radiating patch, cutting the edges of the radiating patch, by slotting different shapes in the radiating patch [49] and feedline, using split ring resonators [40], designing fractal patch [46] and employing EBG in the antenna structure [41].

The phenomenon behind band notching is surface current distribution at the resonating structure. The flow of current is different in the parallel structure line which leads to band notching. The center frequency of the notch band can be controlled by varying the lengths of the resonating structure. Filtering property is the major property of band notched structures, applying external filter to an antenna can make it bulky and large so for filtering unwanted signals intrinsic filters using is a suitable choice. The proposed design in this thesis used resonating structures coupled with the radiating patch which is one of the techniques to attain band notch characteristics. The gap between resonating structure and feedline act as a stop band filter. In other techniques for example slit/slot are etched from the patch which also shows filtering characteristics. There are many band notching

techniques but in the proposed design we have used the most simple and easily reconfigurable design with ease of fabrication.

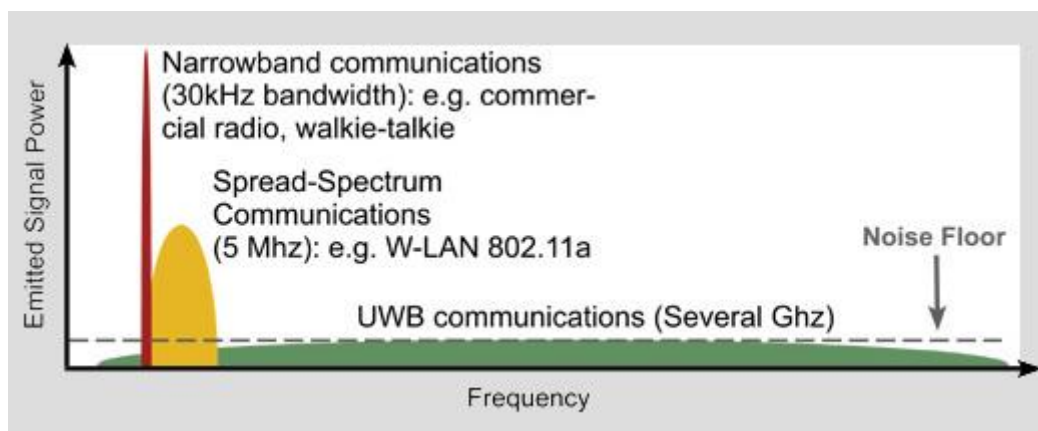


Figure 1.1 Spectrum comparison of Ultra Wide Band and narrowband signals [6].

Band notching technique does not cover the whole bandwidth therefore there is a need of reconfigurable antennas which overcome this problem [20-23]. Along with wide bandwidth there is a need of the feature which incorporates many antennas into one in order to fulfill the demand of getting different services in one terminal. For the same reconfigurable antennas are used which can control many characteristics like frequency tuning, radiation pattern and polarization. Reconfigurability can be achieved by combining antennas of different shapes and sizes but they are categorized according to the functionality of the reconfigurable antennas. They are namely frequency reconfigurable antennas, pattern reconfigurable antennas, reconfigurable polarization antennas and hybrid antennas which is the combination of above three antennas [38]. In frequency reconfigurable antennas frequency tuning is achieved by using different types of switches like MEMS [38][57], PIN diodes [51], varactor diodes or by physically changing the configuration of the antenna. Using different types of switch change the surface current distribution which changes notch band position and leads to reconfigurability [26-27].

1.2 MOTIVATION

In recent wireless systems, multiple antennas are needed so that they can provide multiple communication services which make wireless systems complex and bulky along with more power dissipation. Frequency reconfigurable antenna use single antenna replacing multiple antennas which makes system hefty. Combining various antennas with different characteristics makes antenna more useful and also reduce the size. Reconfigurability gives extra advantage over non reconfigurable antennas that it provides flexibility of operations and pre-filtering properties that filter interfering signals at the receiver end.

UWB technology now a days have uplifted popularity because of its highlights namely low power spectral density, high data rate and minimal cost. UWB is suitable for many applications like indoor application, high data rate multimedia applications, locating and positioning objects in critical conditions and also in radar applications. Designing antennas in the UWB range have various advantages along with band notching which filter out unwanted narrowbands of other wireless systems [52].

Band notching technique does not cover the whole bandwidth therefore there is a need of reconfigurable antennas which overcome this problem. Reconfigurability generates systems that are low profile, low weight, minimal cost and energy efficient. So researchers are studying frequency reconfigurable UWB antennas to make single antenna which incorporates and release the same band according to the demand. A frequency reconfigurable antenna is proposed in this thesis using RF switch for notching two bands. Reviewing various papers leads to the motivation that there is requirement of more reconfigurable antennas in the UWB range.

1.3 OBJECTIVE OF THE THESIS

The main objective of this thesis is to design a frequency reconfigurable UWB antenna. In this work, an innovative planar microstrip UWB antenna with dual band rejection is proposed which is further made reconfigurable by employing RF switches in the design.

- I. To design and analyze ‘E’ shape filter structure.
- II. To design a notch reconfigurable UWB antenna using reconfigurable ‘E’ and ‘C’ shape filter structures using RF switches.
- III. To fabricate and test the proposed notch reconfigurable UWB antenna.

1.4 OUTLINE OF THESIS

Chapter 1: provides an introduction of the research respectively, the motivation to start this work and thesis objectives. The chapter includes introduction of UWB technology, the applications of UWB technology and need of reconfigurability along reconfigurable UWB band notch characteristics with the help of various switches.

Chapter 2: introduces a literature review related to the UWB antenna designs, band notching techniques used in UWB antenna design, coplanar UWB antenna designs, different techniques to achieve reconfigurability and various frequency reconfigurable UWB antenna designs. The literature review covered the complete background of other related research works of reconfigurable antenna parameters.

Chapter 3: explains the equivalent circuit of the filter used in the reconfigurable antenna design along with the typical discontinuities equivalent circuits. The design equations are also explained for bent structure, T junction and simple transmission line.

Chapter 4: presents the design the basic circular patch UWB antenna. The filter structure we have designed and discussed in the previous chapter is employed in the basic circular patch UWB antenna. Parametric study of the lengths of the resonating structure is also discussed in this chapter. Reconfigurability of the notches is obtained by employing RF switches at appropriate places.

Chapter 5: represents the proposed fabricated antenna. Measured results are discussed and compared with the simulated results. Gain, VSWR and radiation pattern of the notch reconfigurable antenna are discussed in this chapter.

Chapter 5: includes conclusion of the research work and outfits suggestions for any future work about reconfigurable antennas.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

In this chapter various papers related to the title of the thesis are briefly explained. Initially, UWB antennas are presented and then various band notching techniques are studied and compared. Multiple antennas that can be combined to form single antenna are reviewed. Further to improve fixed bandwidth notching designs and to improve UWB performance various reconfigurable structures are presented.

2.2 SUMMARIZED RESEARCH PAPERS

[17] **J. Liang *et al.* (2004)** proposed a printed circular disc antenna which resonates in UWB band from 2.78 to 9.78 GHz. Parametric studies has been done and optimum value of feed gap and width of the ground plane are decided in determining antenna's performance. Variations in feed gap changes operating bandwidth of the antenna due to impedance matching, optimized feed gap was 0.3 mm for fixed width. Width of the ground plane affects the performance of antenna because the current distribution is mainly on the upper edge of the ground along y direction.

[18] **A Vishawanatham *et al.* (2014)** studied the effect of partial ground plane on circular patch micro-strip circular patch antenna characteristics – efficiency, impedance matching, front to back ratio, bandwidth. Reduction of ground plane enhances bandwidth of UWB circular micro-strip antenna. Radius of the circular disc was calculated through cavity model formulations. Most suitable configuration of design was identified in terms of Gain, S11, and VSWR. Other techniques for bandwidth enhancements are feed gap optimization, beveling, segmentation in the patch and different feeding geometries.

[19] **Ke Zhang *et al.* (2010)** presented a novel segmented circular UWB antenna which has band rejection property at 5.1 GHz to 6.1 GHz for WLAN. When surface current and E Field analyzed at 3 GHz, the current distribution is less at edges of slots and side patches. E Field and surface current which explains current flow is severe at 5.7 GHz along the edges of the slots which leads to band rejection. This segmenting method is easy and further used for various patch shapes, for example, ellipse, pentagon, polygon, etc. for achieving band rejection characteristics.

[20] **Z. Wang *et al.* (2015)** incorporated SRSSLR in a simple circular monopole antenna to achieve tunable triple notch band. Impedance matching is achieved by embedding rectangular slit in the ground plane. Tuning of desired notch band is controlled by the parameters of proposed square ring

short stop loaded resonator (SRSSLR). The proposed antenna rejects C-band satellite communication systems, WLAN, RFID services. Design exhibits significant antenna gain decreases at 4.01, 5.25, and 6.79 GHz, this is representing the effect of rejections in UWB frequency response.

[21] **R. Azim et al. (2012)** presented a design which is not complex as other designs for example isolated slits in patch, semicircular slot in elliptical slot require large ground plane. Two frequency notches, one WLAN and other WiMAX are obtained without using additional filters. Simple design is achieved by inserting one 'e' and one 'c' shaped parasitic element on the back side of the rectangular patch. To improve impedance matching upper edge of the ground plane is modified and formed like symmetric sawtooth wave.

[22] **X. Liao et al. (2010)** combined conventional methods; put parasitic elements near printed patch, slot the different shapes from patch and defecting ground plane, which separately were not effective for great antenna performance. The circular patch antenna contains ellipse shaped slot on front side and attached parasitic strip in ground plane, which leads to one notch band (WLAN). WiMAX notch band is achieved by etching hook shaped slots in the ground plane. Additionally proposed antenna has a small size 24x26x1 mm³.

[23] **Ki-Hak Kim et al. (2006)** designed antenna which composed of a circular ground with a slit, a half ellipse-shaped radiation patch with an ellipse-shaped slot and a parasitic strip attached in the ground plane. The ellipse shaped slot leads to wider bandwidth performance, optimized steps in the slot leads to good VSWR at 10 GHz. Variations in the steps size and length of parasitic element affects coupling between the planar ellipse monopole and the ground plane that helps in fine tuning of impedance matching.

[24] **R. Azim et al. (2013)** proposed a different antenna with a tuning stub that are rectangular in shape and a ground plane with a tapered-shape slot. One bent parasitic slit and tuning stub are etched out and two symmetrical parasitic slits are placed in the slot of the ground plane for WiMAX and WLAN notch bands respectively. Current flow is dense around parasitic slit and the direction of current in slit is opposite to the exterior edges of the ground plane. Therefore, effective radiation is reduced and notch band is created at 3.5 GHz. The designed antenna can be for line of sight wireless communication applications.

[25] **R. Azim et al. (2014)** proposed one simple filter element to notch dual frequency. A tri-arm resonator is etched in the ground plane. The real part of input impedance characteristic of the proposed antenna far away from 50 Ω leading to mismatch around notched frequencies (3.5GHz and 5.5GHz). Despite some mismatches, the proposed antenna behaves similar to the antenna without tri arm resonator which has characteristic impedance close to 50 Ω . Length of the ground plane is optimized for good antenna performance.

[26] **B. Badamchi *et al.* (2014)** proposed a compact reconfigurable rectangular patch antenna for UWB applications. UWB characteristics are achieved by etching two symmetrical slots on the feedline. Then, by cutting two inverted U shaped slots from rectangular patch and adding two PIN diodes along these slot four different notch performances are achieved. The designed antenna has a small size of $20 \times 20 \text{ mm}^2$ and the UWB frequency spectrum with switchable band notch characteristics at 3.15–3.85 GHz and 5.43–6.1 GHz which can rejects interferences with the WiMAX, the C-band and the WLAN systems.

[27] **H. Oraizi *et al.* (2017)** proposed reconfigurable antenna which has inverted L (Γ) shaped parasitic element placed in the slot of patch to create the band notch at 5.1–5.7 GHz and has rectangular split ring resonator (RSRR) placed on the back side of antenna to create a band notch at 7.2–7.8 GHz. Since this antenna covers UWB range, its performance is analyzed in both frequency and time domains. Reconfigurability is created by placing PIN diodes at appropriate places, four different operations are observed. Namely (1) whole UWB spectrum, (2) UWB spectrum with notch band at WLAN, (3) UWB spectrum with band notch at X-band downlink and (4) UWB coverage with two notch band at WLAN and X band. The appropriate place of PIN diode was obtained by studying the current distribution on the inverted Γ - shaped strip.

[28] **V. Sharbati *et al.* (2016)** proposed a compact reconfigurable antenna with size $17 \times 14 \text{ mm}^2$ which operates in ultra wideband. Switchable notch bands; 3.25–4.26 GHz, 5.1–5.6 GHz or 7.1–7.8 GHz are achieved through three p-i-n diodes. Various methods (square ring slot in rectangular patch antenna, L-shaped parasitic element attached with patch and in the ground plane two rectangular structure are placed) has been used to create band notches. By changing PIN diodes status, band notches are made applicable in WLAN, WiMAX/C-band and X band applications.

[29] **Ming C. Tang *et al.* (2016)** proposed a unique antenna which continuously tunes bands that are notched. First band notch occurred when a rectangular strip is placed on the inverted T slot rectangular patch. For the second band notch, U molded resonator is placed exactly below the radiating patch. Varactors diodes were placed appropriately on the parasitic elements to ensure frequency agility. Minimum numbers of varactor diodes were used for independently controlling upper and lower notch bands. The designed compact UWB antenna was right for cognitive radio applications.

[30] **Dinesh Yadav *et al.* (2017)** proposed switchable notch characteristics at 5.3 GHz by using F shaped resonator and three rectangular stubs located on the ground plane. UWB characteristics with reconfigurable rejection bands are obtained using p-i-n diodes connecting stubs and the F shaped parasitic elements. All diodes are off results in the UWB gamut with 4.9 to 5.7 GHz band notch and all diodes on results in switching rejection band into radiating band which is at 5.3 GHz (WLAN band). Also to increase impedance matching defected ground structure (DGS) is used. Surface current

distribution analysis shows that current is mainly concentrated around parasitic strip. When diodes are off current flow is opposite in parasitic strip and edges of rectangular patch that leads to band rejection. And when diodes are on, flow of current is same in parasitic strips and edges of patch that develop radiating antenna in UWB band.

[31] **L.Y. Cai *et al.* (2010)** studied different band notching techniques involving etching slots on ground and patch, attaching moulds of different shapes from radiating element or ground plane and concluded they independently cannot provide efficient notching characteristics. To overcome this, fork shaped antenna with independent strips can be used but lack in miniaturization. For reducing the size and achieving band notch functions of antenna author had proposed I shaped, H shaped and U shaped strips etched on the radiator. These types of antennas can be used in various wireless devices.

[32] **Daeheon Lee *et al.* (2013)** proposed tapered antenna for dual band notches. First notched band is achieved by placing C shaped structures on each side of feedline. Second notched band used for averting WLAN systems is achieved by spiral shaped slot connected to the microstrip feedline. Slot and stub behavior does not affect the original antenna characteristics. Equivalent circuit models have been studied to understand filtering properties. Parameters are studied to adjust the center frequency of the notch bands. VSWR is less than 2 for the proposed antenna in the range of 2.4 to 11.6 GHz expect in the band 3.3 GHz -3.7 GHz and 5.15 GHz -5.825 GHz, which makes it good choice for UWB applications.

[33] **A. M. Abbosh *et al.* (2009)** designed four antennas for UWB applications. Parasitic strips are located beside the radiating aperture and ground plane that are half circles with diameters equal to length of the antenna structure. Four samples has been designed; (1) without parasitic strips which results in UWB coverage, (2) with parasitic strips which notch a narrow band(5 – 6 GHz), (3) with wide parasitic strips which notch wide band(4 – 7 GHz) and (4) three small parasitic strips to notch three narrow bands(4.5 – 5.5 GHz, 6.5 – 7.5 GHz and 8.5 – 9.5 GHz). Tapered ends parasitic elements are used in the design along radiating patch in order to reject certain frequency bands. The same is proved mathematically and measured results are in good agreement to the mathematical results.

[34] **P. S. Suresh *et al.* (2012)** proposed a simple technique for band notching. Beveling ground plane edges and using parasitic rectangular strips nested around radiating structure which has same width as parasitic strips but increased length. Length of the radiating patch is similar to quarter wavelength. Return loss is less than – 10 dB for 27.2% bandwidth which complete UWB range. Beveling is used by many authors to remove interference causing bands. But the drawback of beveling is that it decreases the gain of the antenna.

[35] **M. M. Sharma *et al.* (2012)** studied techniques that involve slotting in the radiating patch and feedline for achieving UWB coverage but these techniques constrained to limited feed line width to

get 50 ohm impedance. So other way to achieve the same is to encompass DGS and SRR in the ground and radiating patch respectively. DGS is achieved by slotting same slits in the coplanar ground plane. CST was used to analyze the performance of the antenna. Dual notches were created and gain was reduced to about 7.74 dBi and 4.27 dBi at notch frequencies.

[36] **Amit Chauhan *et al.* (2014)** proposed a antenna with DGS and slots in the the radiating patch for UWB applications. Increasing the number of slot increase the uniformity of reflection coefficients and reduce the parasitic effects. The proposed antenna use Rogers 5880 substrate with relative dielectric constant of 2.2. Antenna is more efficient when resonating frequency increases from 3 to 10 GHz. Equivalent structure are shown using Ansoft designer and also mathematically calculated.

[37] **A K Gautam *et al.* (2013)** designed UWB antenna as MSA's does not have broad bandwidth and multiple resonance. The proposed antenna has coplanar ground, unlike conventional antennas with ground plane at the back of substrate. The radiating patch has nested inverted L shaped structure with CPW fed on the patch's left and right side on the similar plane. Comparison is shown through return loss of different radiating patch; rectangular, U slotted rectangular patch and proposed antenna, with same CPW ground plane. And proposed antenna has best return loss of less than -10 dB and three resonant frequencies at 3.03, 6.11 and 11.78 GHz. Group delay is almost constant which fits for UWB applications.

[38] **S. Nikolaou *et al.* (2009)** suggested two CPW fed antennas for switching between UWB coverage and UWB coverage except a narrow band. MEMS switches are used as they do not require bias lines. In first antenna U slot is created in the elliptical patch which have tapered CPW and tapered feedline. MEMS are integrated in the slot and short the slot when notch bands (HIPERLAN, WLAN) are not required. In the second antenna, inverted L shaped resonators are placed symmetrically above the elliptical patch and same ground plane as first antenna. Two MEMS switches are integrated which connects resonator and the elliptical patch. Slot position and stub position affects the antenna performance, slot position strongly affect the performance as due to strong current at the radiating patch coupling is more with U shaped slot. Radiation patterns were studied and verified that radiated fields degrades in the rejection band through gain measurements.

[39] **F. D. Dahalan *et al.* (2013)** chose an Archimedean spiral antenna with four number of turns as basic structure because it provides circular polarization over wide bandwidth. CPW feed is selected and feeding is provided to the structure by aligning two arms together. To make the structure capable for narrow bandwidth systems pair of meandered slots are etched along the feedline. For attaining frequency reconfiguration two p-i-n diodes are inserted in the slots etched around feedline. When diodes are ON filtering effect is eliminated and wide band is achieved (2-8GHz). Narrowband (5.1-5.9 GHz) is tuned when diodes are OFF. Efficiency of antenna is 45% due to the losses developed by p-i-n diodes. Reconfigurability is achieved between wideband and narrowband in the proposed antenna.

[40] **M. Al-Husseini *et al.* (2013)** designed two antennas printed on Rogers RO3006 substrate. Beveled rectangular patch is used for first design and CSRR's are nested in the tapered patch. Switches are inserted in these CSRR's causing the surface area of CSRR smaller (or larger) which gives notch band at higher (or lower) frequencies. For second design two SRR are etched on either side of the feedline, switches are inserted in the center of SRR. When switches are ON, SRR works and achieve rejection band that are desired. When switches are OFF, design again radiates in UWB range.

[41] **H. A. Majid *et al.* (2014)** proposed a unique design for reconfigurable UWB antennas using EBG. The proposed front design consists of circular patch antenna and two EBG structures placed along feedline of radiating patch. Taconic RF-35 of height 1.53 mm is used as substrate material and V slot is inserted in the ground plane for better impedance matching. Two square shape EBG structures shorted to the ground using via are used to attain desired rejection bands (3.97 and 5.51 GHz). To activate and deactivate connection of EBG to the ground, switches are inserted on the circular slot around vias. Four different performances are exhibited by enabling and disabling switches. Size of EBG decides the rejected bands, EBG1 notches higher frequency bands and EBG2 notches lower frequency bands. When all switches are on dual band is rejected, when all switches are off UWB coverage is observed. When EBG1 is disabled notch band at 3.97 GHz is observed and when EBG2 is disabled 5.51 GHz notch frequency is obtained.

[42] **M.K.A. Rahim *et al.* (2016)** studied conventional methods of fixed band notching is improved by reconfigurable antennas to completely use UWB frequency range. In some cases, like above paper perturbation in radiating patch disturbs radiation pattern. To overcome this perturbation EBG is used in reconfigurable antennas. One of the designs of the proposed paper used two layers of Taconic RF-35 substrate. Top layer consist of radiating patch which is wine cup shaped, the second layer consist of mushroom like three EBG structures aligned below the feedline of the antenna. The Last layer contains biasing circuits and p-i-n diode is inserted between square patch and the stub. When diode is on, square patch gets connected to the ground that notches 1.82 GHz, 2.27 GHz and 2.58 GHz frequencies. The proposed antenna can be used for wireless communication applications.

[43] **S. Kumar *et al.* (2016)** proposed UWB band pass filter with triangular ring like stub placed above multimode resonator and ground plane contains two rectangular apertures. The measured 3 dB range is from 3.09 GHz – 10.618 GHz with skirt factor 0.975. E and C molded resonators are placed longitudinally along TRLSR, firstly when single C molded resonator is placed on the MMR 3.6 GHz frequency is notched. Then two C molded resonators are placed on the MMR which results in two independent notches at 5.2 GHz and 8.4 GHz. If C molded resonators are replaced by E resonator two concurrent notches occurs at 5.2 GHz and 8.4 GHz. The middle frequency of rejection bands are controlled by varying lengths of the resonators.

[44] **R Srivastava *et al.* (2016)** proposed a reconfigurable UWB bandpass filter. The basic structure consists of feedline and coupling gaps for coupling power. Further design is composed of E and C shaped structure which can be reconfigured to one another using switches. The reconfigurable structure is placed above multimode resonator. MMR consist of stepped impedance resonator which changes the resonant frequency if its impedance is varied. SIR consists of different impedance regions. When E configuration is selected two notch bands are created with center frequencies 5.2 and 9.75 GHz. When switches are in OFF state C shape is reconfigured and single notch band is created at 5.2 GHz. The middle frequency of rejection bands are controlled by varying lengths of the resonators.

[45] **Raviraj C. Jain *et al.* (2015)** studied various band notching techniques and compared them for different antenna performance. Techniques are tuning stub, parasitic element, different slot shapes, SRR or CSRR slots, fractal geometry antennas are studied. Band notching techniques are used to avert interferences from other popular bands. Maximum techniques achieve band notch characteristics without affecting antenna performance. Tabular comparison is presented in this paper which helps to find correct technique for desired notch frequencies.

[46] **M. R. Azadi Naeini *et al.* (2014)** proposed a CPW fed which have fractal patch that notches a band from 4.65 to 6.08 GHz. The slot is removed from the center of ground plane of dimension 40x30 mm². CPW feedline has 2 mm width and slot gap of 0.12 mm. The design covers the range from 3 – 10 GHz and rejects band of WLAN system. Average gain of 1.86 dB and acceptable radiation characteristic is observed. The surface current distribution is presented, at notch frequency 5.2 GHz flow of current is inversed which do not make antenna to radiate at this frequency.

[47] **X.S Yang *et al.* (2005)** proposed a different technique of band notching. Radiating structure is made by third order Hilbert curve (kind of fractal geometry). This Hilbert curve antenna used to design reconfigurable antenna which reduces the overall size of antenna. MEMS switches are used in the Hilbert third order structure to switch between two configurations. Coaxial probe was used to feed this antenna. Four narrow slots was etched in the patch to change the current distribution around the feeding point. Six MEMS switches are inserted in these slots and two configurations was generated. Both configurations radiates in the band 12.34 to 12.65 GHz with bandwidth of 2.48%.

[48] **M. Moosazadeh *et al.* (2012)** designed an antenna from simple rectangular patch and small rectangular ground plane. Square patch and two inverted L shaped are slotted from the rectangular patch and developed first notch band at 3.75GHz. Inverted T shaped strip is etched inside the square slot which creates second notch at 5.48 GHz. To improve the antenna performance pi shaped structure is placed on the ground plane. The performance has improved in the band 9.8 to 10.6 GHz making it good for UWB applications. Current distributions were discussed and show the phenomenon of non radiation at notching frequencies. VSWR values in the range 2.5 GHz to 10.8 GHz shows good impedance matching except the notched band (3.2 to 4.2 GHz and 5 to 5.9 GHz). To reduce the

effects of cable on the antenna performance ferrite beads are used with cable to reflect or absorb the induced power on the cable.

[49] **A. Chaabane *et al.* (2014)** proposed a modified ground antenna with reduced size and shape and which provides pure resistive input impedance. A rectangular slot is further cut from the ground to get better impedance matching. The radiating patch was half moon shaped and was tapered from bottom with a staircase structure. By varying the staircase dimensions and optimizing them lead to wider impedance bandwidth. Small size of printed patch and ground plane are the significant factors for UWB bandwidth. Dual band notch is created by slotting inverted U molded structure from the basic patch and U shaped slot was removed from feedline. The middle frequencies of the notches are dependent on the total length of the slot. It was observed from the parametric study upper notch band can be adjusted by varying inverted U slot in the patch and lower notch band can be adjusted by varying length of vertical U slot in the feedline. The proposed antenna works in the entire UWB range with 80% radiation efficiency and stable peak gain except 3.20 GHz – 4.1 GHz and 5.2 GHz – 5.96 GHz.

[50] **C.-Y. Huang *et al.* (2008)** proposed a compact antenna design with modified circular patch with small microstrip feedline inside a ground with a circular slot. An inverted C shaped parasitic stub is placed above the circular patch inside the ground on the same plane. The compact size of antenna is 26 x 28 mm² and FR4 substrate with 0.4 thickness. The flare angle of parasitic strip change the band rejected characteristics, sharp band notches appears when flare angle is large. Other parameters that affect the notching characteristics are width and inner angle of the parasitic strip. After optimization of the parameters affecting antenna performances, UWB coverage except 5.2/5.8 GHz band was achieved.

[51] **D. V. Niture *et al.* (2017)** designed a reconfigurable antenna using a circular disc and partial ground plane with a rectangular slot at the top partial ground. By optimizing parameters like gap between ground and patch, radius of circular patch, length and width of ground plane UWB coverage was attained. For obtaining notch frequencies rectangular slot was cut from the ground plane. Reconfigurability was obtained by employing switches at appropriate places. Three switches namely S1, S2 and S3 were placed accordingly in the slot generating three configurations. When S1 was off three slots were created which notch the frequency 3.1 GHz due to the current distribution in the slotted area. When S2 was off second notch band was created at 8.3 GHz with bandwidth of 3.05 GHz. When all the switches were on it operates in whole UWB range. This antenna is good option for cognitive radio applications, WiMAX and various wireless communication systems.

[52] **S. Ullah *et al.* (2009)** discussed the applications of UWB technology. There is great advancement in the wireless communication fields, to meet the demands UWB is the correct measure. This paper briefed the application for low data rate, high data rate, radar, position and location tracking. UWB is

suitable for indoor applications, for computer peripherals like mouse, keyboard, printer etc. for making reliable connection. Pulse UWB scheme is explained in this paper which can be used for WBAN applications. WBAN comprises of small, minimal power and wireless sensors, which are implanted in humans in order to provide better healthcare information. Therefore UWB plays a vital role in future innovations in medical field.

[53] **MK Meshram *et al.* (2001)** proved that microstrip array antenna which gap coupled have better impedance matching and bandwidth than usual microstrip array antenna. Gap in the microstrip array antenna plays important role so its equivalent circuit and design equations have been explained. Antenna design contains four gap coupled rectangular patches and feed is equally provided to each of them. Design consideration includes RT-Duroid as substrate, resonating frequency 3 GHz and gap length of 1.5 mm. Study showed that increasing gap length reduces the resonant frequency, also input impedance depends on the gap length. VSWR is low for gap coupled microstrip array than conventional antenna array. Radiation performance is improved for both gap coupled and conventional antenna array along with large bandwidth.

[54] **H Siahkamari *et al.* (2016)** proposed a filter design that includes modified T shaped resonator, radial patch and rectangular shape resonators in order to get ultra wide stop band. Modified T shaped resonator is used to provide sharpness in the transition band, radial patch and rectangular patch are used to attain low insertion loss and wide stop band. Equivalent circuit is calculated to improve sharpness in the transition band. Further transmission zero and transfer function is also calculated in this paper from LC equivalent circuit. The figure of merit of the proposed low pass filter is very high 41389 which desirable for advance wireless communication.

[55] **Gurpreet Singh *et al.* (2013)** compared microstrip planar antenna and defected ground MPA and concluded that defected ground gives better impedance matching, broad bandwidth, good return loss and VSWR close to unity. This research paper added G shaped defected ground structure to the microstrip planar antenna. Design equations of rectangular patch were discussed along with equivalent circuit which helps to understand antenna characteristics. Current distribution changes when ground plane is defected as it includes more capacitance and inductance effect. Bandwidth improved by 598.4 MHz and with return loss of -49.43 dB. The proposed antenna provides applications in C band , Wi Fi and satellite communication.

From the literature survey it is clear that reconfigurable antennas are required to make one antenna perform various functions. In the next chapter phenomenon behind the filtering of undesired band is explained.

CHAPTER 3

ANALYSIS OF 'E' SHAPED FILTER STRUCTURE

3.1 NEED OF FILTER PROPERTIES IN UWB ANTENNAS

Currently, there is heightened interest in UWB applications for wireless communication systems due to its good features such as high data transmission rate, low spectral power density and low cost [5]. Many antennas have been designed for UWB applications using various techniques. The UWB works in the range from 3.1 – 10.6 GHz, interferences from many existing narrow band is ensured. Narrow band systems are WiMAX, WLAN, C and X band satellite communication system. To avert the interferences from these narrow bands UWB antenna need to be incorporated by filtering properties [36]. Filters can be used for the purpose of trashing out frequencies which are already in use [43-44]. But implanting external filters to the present UWB antenna makes its size large and inserts more losses in the circuit. So the intrinsic filter properties are required for UWB antennas rather than external bandstop filters to reduce computational properties of the signal processing and minimizing the cost of overall device. Different designs have been discussed in the literature survey involving band notch techniques for UWB applications. Different techniques are segmentation, slotting, tapered slotting and placing parasitic elements in the radiating patch, feeding line and the ground plane [45]. These techniques only notch the required frequencies without varying the passband of UWB antenna designs.

3.2 FILTER IMPLEMENTATION

For designing practical microwave filter equivalence between lumped elements and transmission line (distributed elements) is required. Richard's transformation is used to form such equivalence. The input impedances of transmission line (open and short circuited) given by

$$Z_{in^s} = jZ_o \tan \beta l \quad (3.1)$$

$$Z_{in^o} = jZ_o \cot \beta l \quad (3.2)$$

where Z_o is characteristic impedance of transmission line, β is propagation constant and l is the length of transmission line [7].

The input impedances are purely reactive but reactance of lumped elements (inductors and capacitors) is different mathematically as shown below

$$Z_L = j\omega L \quad (3.3)$$

$$Z_C = \frac{-j}{\omega C} \quad (3.4)$$

However, for a given lumped element (L or C) and transmission line (with given characteristic impedance and length) the functions will be equal at frequency ω_c , that satisfies the following equation

$$j\omega_c L = jZ_o \tan \beta l \quad (3.5)$$

$$= jZ_o \tan \frac{\omega_c l}{v_p} \quad (3.6)$$

Similarly, satisfies the equation

$$\frac{-j}{\omega_c C} = jZ_o \cot \beta l \quad (3.7)$$

$$= -jZ_o \cot \frac{\omega_c l}{v_p} \quad (3.8)$$

Set the lengths of the transmission line to $\lambda_c/8$ to make calculations easier where $\lambda_c = \frac{v_p}{\omega_c} =$

$$\frac{2\pi}{\beta_c}$$

$$j\omega_c L = jZ_o \tan \frac{\pi}{4} = jZ_o \quad (3.9)$$

$$\frac{-j}{\omega_c C} = -jZ_o \cot \frac{\pi}{4} = -jZ_o \quad (3.10)$$

Therefore to construct a transmission line (short circuited) with same impedance as an inductor L at frequency ω_c then characteristic impedance of the transmission line will be $Z_o = \omega_c L$

Similarly, to construct a transmission line (open circuited) with same impedance as a capacitor C at frequency ω_c then characteristic impedance of the transmission line will be $Z_o = \frac{1}{\omega_c C}$.

3.3 CIRCUIT ANALYSIS OF VARIOUS RESONATING STRUCTURES

3.3.1 Equivalent circuit of microstrip line

Microstrip lines or planar transmission lines are distributed parameter networks. A transmission line is generally represented as two wire line since microstrip patch antennas have minimum two conductors [8]. Figure 3.1(a) shows the two wire line representation of transmission line and figure 3(b) represents its equivalent circuit.

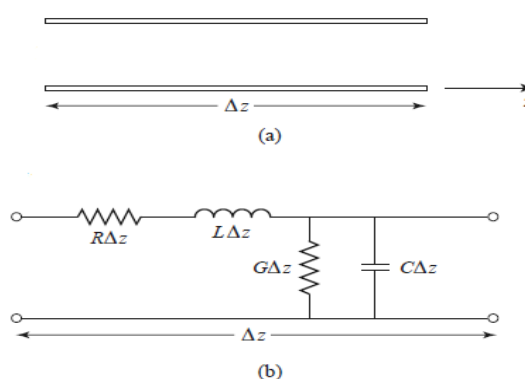


Fig. 3.1 (a) Transmission line representation and (b) its equivalent circuit [8].

Planar microstrip circuits are easy to fabricate as they integrate many active and passive components. Performance of microwave planar circuits can be perturbed by bends, step change and junctions. So in order to improve circuit's performance chamfering (cut right angles) of the edges can be done.

Microstrip lines have two guided media that are dielectric substrate and air. Microstrip lines does not support pure TEM wave which has only transverse components but rather support quasi static TEM wave due to two guided media which have longitudinal components of E and H field [9].

When the resonator and microstrip feedline are in close proximity power can be coupled from one line to another due to interactions of EM fields in them. The level of coupling can be change according to applications and is given by the factor coupling coefficient. The coupling of the resonator to the feedline has the effect of lowering its resonant frequency [10]. The gap between the coupled resonator and microstrip feedline can be represented as series capacitor and its equivalent circuit is shown in the figure 3.2, where Z_0 is the characteristic impedance of feedline, Z is the input impedance and ℓ is the length of the resonator with Z_0 characteristic impedance.

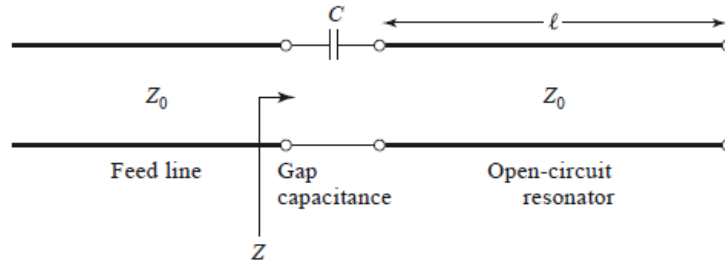


Fig. 3.2 Equivalent circuit of gap coupled microstrip line and open circuited resonator.

3.3.2 Equivalent circuits typical discontinuities

When a hot conductor encounters change in dimension or change in dielectric constant than we can say discontinuity is present. Discontinuities causes signal attenuation, coupling and crosstalk in microstrip antennas [11]. Power radiated when discontinuities are involved in the radiating structure or among microstrip lines in the radiating area is given by:

$$W_r = \frac{240(\pi h)^2}{Z\lambda_0^2} F_r[\epsilon_{re}] \quad (3.11)$$

where:

h is the substrate height

Z is the microstrip impedance

λ_0 is the free space wavelength

$F_r[\epsilon_{re}]$ is the radiation function which depends upon the type of discontinuity and the effective dielectric constant ϵ_{re} of the microstrip antenna.

Here are some typical discontinuities and their equivalent circuits are discussed. These typical discontinuities are represented in figure 3.5 and their equivalent circuits are presented in next section.

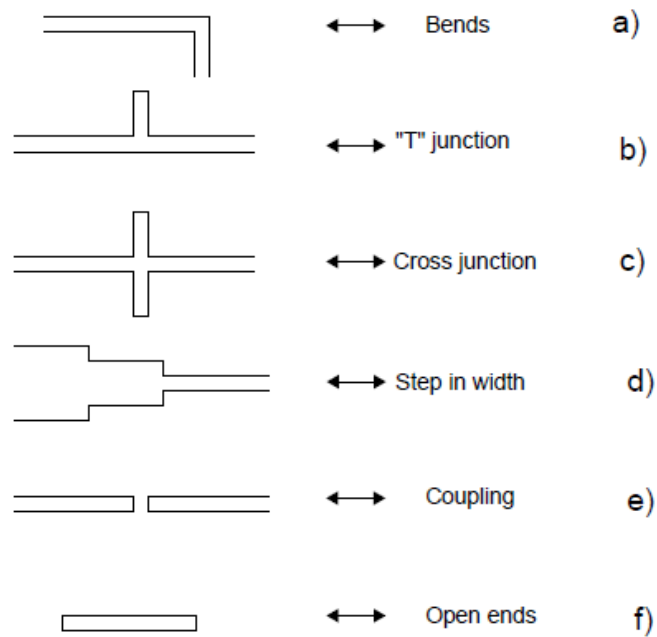


Figure 3.3 Frequent discontinuities in any circuits [7].

- **Bends**

Bends are the most used discontinuity in the antenna designs; figure 3.8 shows bent structure with 90° bend and its equivalent circuit is shown in figure 3.4.

- **Open Ends**

Every antenna design composed of an open end structure, which means structure is not further connected to any transmission line. Figure 3.5(a) shows an open end structure and figure 3.5(b) represents its equivalent structure

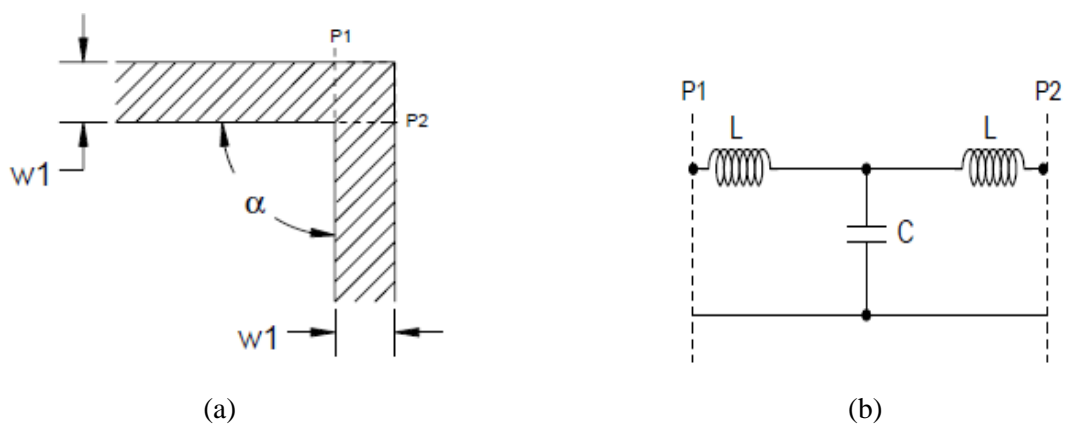


Figure 3.4 (a) Bent Structure and (b) its equivalent circuit [7].



Figure 3.5 (a) Open End Structure and (b) its equivalent circuit [7].

- **Gaps**

Gaps are the discontinuity which leads to coupling of two unconnected structures. Gap length plays a vital role in the amount of coupling or in the factor coupling coefficient. Figure 3.6(a-b) represents gap discontinuity and its equivalent circuit.

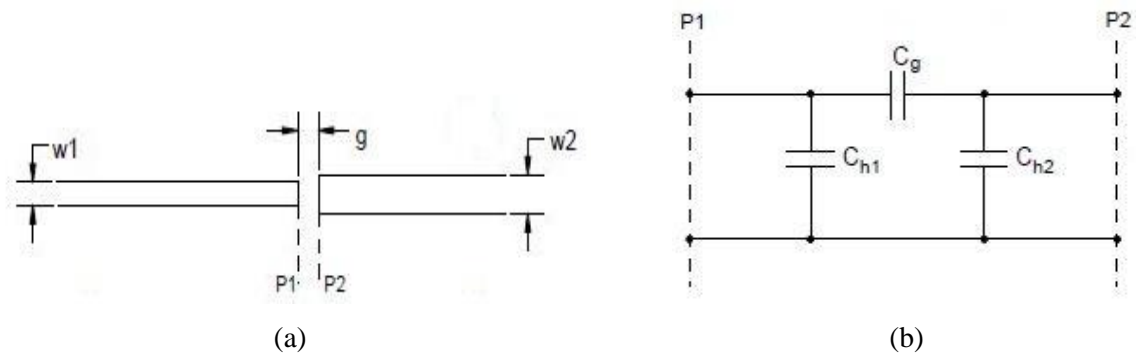


Figure 3.6 (a) Gap Structure and (b) its equivalent circuit [7].

- **Variation in width**

This type of discontinuity is also called step impedance resonator in which width of the stripline does not remain same. Figure 3.7(a-b) represents the variation in width structure and its equivalent circuit.

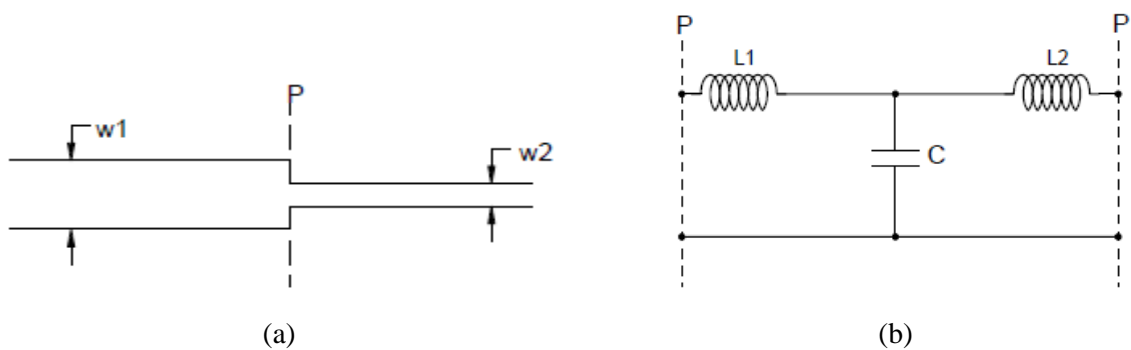


Figure 3.7 (a) Structure representing variation in width and (b) its equivalent circuit [7].

- **T junctions**

T shape structure is a t type of discontinuity which is observed in couplers and matching circuits. The geometry of T junction is shown in the figure 3.10(a) and its equivalent circuit is represented in figure 3.8(b).

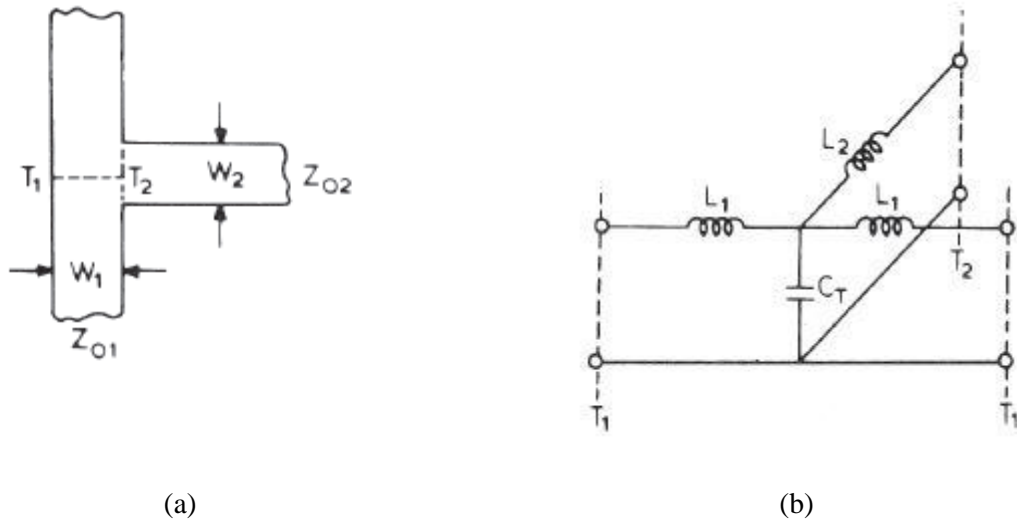


Figure 3.8 (a) T junction structure and (b) its equivalent structure [8].

3.4 CIRCUIT ANALYSIS OF ‘E’ SHAPED FILTER STRUCTURES

E shape resonator structures are designed and implemented as filters by placing them beside the radiating patch’s feedline. The designed filter structures are shown in the figure 3.9. Circuit analysis of the filter structure is presented in this section and its equivalent structure is studied.

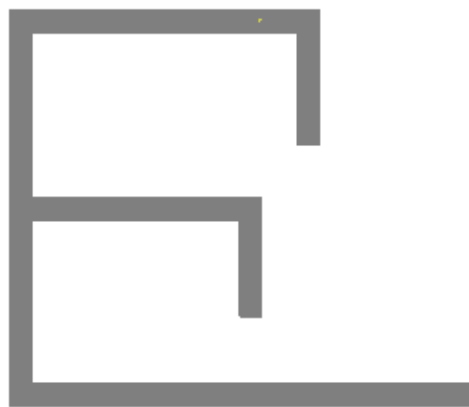


Figure 3.9 ‘E’ shaped filter structure.

3.4.1 Equivalent circuit and design equations of designed filter structure

A filter structure is designed which consist of two symmetric modified E shaped structures placed beside the feedline and is shown in the figure 3.10. Coupling is present between structure and feedline gap. Along with coupling, a bent shape and T junction is present and their circuit analysis is present in this section.

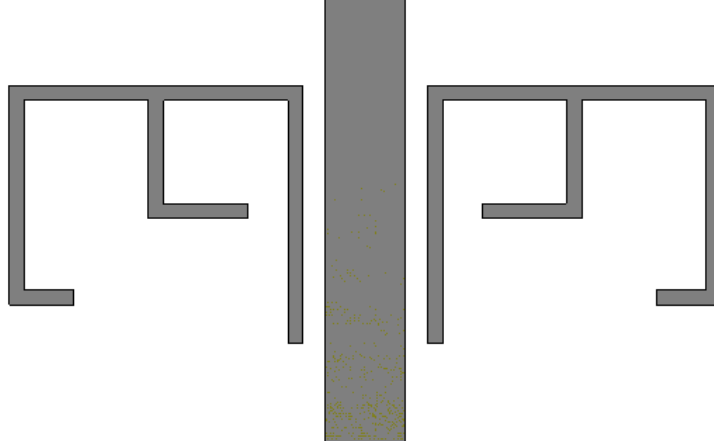


Figure 3.10 E shaped structures coupled with feedline of radiating patch.

The equivalent circuit of the gap between feedline and resonating structure is shown in figure 3.6(a) and figure 3.6(b) represents its equivalent circuit where C_g is mutual capacitance and C_{h1} , C_{h2} are plate capacitances.

According to the research works [13-14] element values in the equivalent circuit shown in figure 3.6 are given by:

$$C_g = 0.5Q_1 h e^{1.86\frac{g}{h}} \left\{ 1 + 4.19 \left\{ 1 - \exp \left[-\frac{0.785 \left(\frac{h}{w_1}\right)^{0.5} w_2}{w_1} \right] \right\} \right\} \quad (3.12)$$

$$C_{h1} = C_{o1}(Q_2 + Q_3)/(1 + Q_2) \quad (3.13)$$

$$C_{h2} = C_{o2}(Q_2 + Q_4)/(1 + Q_2) \quad (3.14)$$

where units of C_g , C_{h1} and C_{h2} is mF and the quantities Q_1 through Q_4 are given by:

$$Q_1 = 0.04598(0.272 + 0.07\varepsilon_r) \left\{ 0.03 + \left(\frac{w}{h}\right)^{\wedge} \left(\frac{1.23}{1 + 0.12 \left(\frac{w_2}{w_1} - 1\right)^{0.9}} \right) \right\} \quad (3.15)$$

$$Q_2 = 0.107 \left(\frac{w_1}{h} + 9 \right) \left(\frac{g}{h} \right)^{3.23} + 2.09 \left(\frac{g}{h} \right)^{1.05} \left(1.5 + \frac{0.3w_1}{h} \right) / \left(1 + \frac{0.6w_1}{h} \right) \quad (3.16)$$

$$Q_3 = \exp \left[-0.5978 \left(\frac{w_2}{w_1} \right)^{1.35} \right] - 0.55 \quad (3.17)$$

$$Q_4 = \exp \left[-0.5978 \left(\frac{w_1}{w_2} \right)^{1.35} \right] - 0.55 \quad (3.18)$$

C_{o1} and C_{o2} are open end capacitances whose equivalent circuit is shown in figure 3.5 and open end capacitance value is shown below

$$C = w \exp \left\{ 2.3026 \sum_{i=1}^{i=5} a_i \left[\log \left(\frac{w}{h} \right) \right]^{(i-1)} \right\} \quad (3.19)$$

The above equation give result in pF/m, and the coefficients a_i are functions of ϵ_r are calculated according to [12].

Next part of resonating structure is bent microstrip line parallel to feed line and its equivalent structure is shown in figure 3.4 having input impedance Z_{o1} . The expression of inductance L and capacitance C are given by

$$C = 10^{-3} h \left[(10.35\epsilon_r + 2.5) \left(\frac{w}{h} \right)^2 + (2.6\epsilon_r + 5.64) \left(\frac{w}{h} \right) \right] \quad (3.20)$$

$$L = 0.22h \left[1 - 1.35 \exp \left(-0.18 \left(\frac{w}{h} \right)^{1.39} \right) \right] \quad (3.21)$$

Here h , C and L have units mm, pF and nH respectively. The above formulas are valid for $2 \leq \epsilon_r \leq 13$ and $0.2 \leq w/h \leq 6$.

For E shaped resonating structure there is a symmetric T junction in the center with input impedance Z_{o2} . The equivalent circuit for the same is shown in figure 3.8. The expression for L_1 , L_2 and C_T are given below [7].

$$C_T = \frac{100w}{\tanh(0.0072Z_0)} + 0.64Z_0 - 261 \quad (3.22)$$

Where Z_0 is the characteristic impedance of the stub

$$L_1 = w \left\{ \frac{w}{h \left(-\frac{0.016w}{h} + 0.064 \right)} + 0.016 / \left(\frac{w}{h} \right) \right\} L_w \quad (3.23)$$

$$L_2 = \left\{ \frac{\left(\frac{0.12w}{h} - 0.47 \right) w}{h} + \frac{0.195w}{h} - 0.357 + 0.0283 \sin(\pi w/h) \right\} L_w \quad (3.24)$$

Where L_w is the inductance per unit length for microstrip line of width w .

Last part of resonating structure is again a bent shape structure with input impedance Z_{03} and its equivalent circuit is similar to first resonating bent shape structure. The equivalent circuit of microstrip line of the circular patch is shown in figure 3.11 and L_L , C_L expression [8][13] are shown here

$$L_L = 100h \left(4 \sqrt{\frac{w_f}{h}} - 4.21 \right) \quad (3.25)$$

$$C_L = w_f \left\{ \frac{(9.5\epsilon_r + 1.25)w_f}{h} + 5.2\epsilon_r + 7 \right\} \quad (3.26)$$

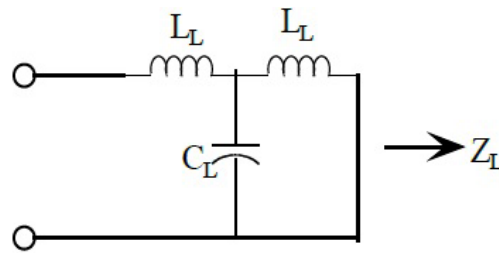
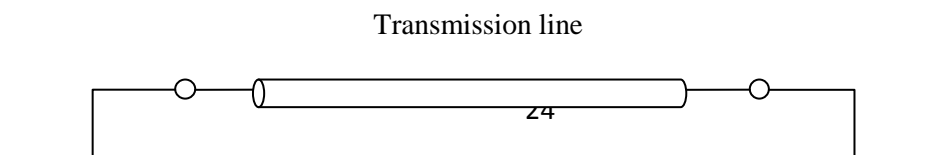


Figure 3.11 Equivalent structure of microstrip feedline [8].

The designed structure has two symmetrical sections parallel to the microstrip feedline. The designed structure is shown in figure 3.12. The equivalent of section I is shown in the figure 3.13 and equivalent circuit of section II is similar to section I.



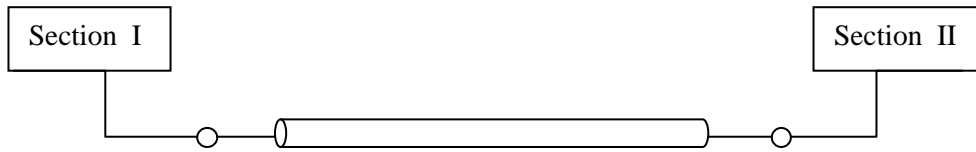


Figure 3.12 Equivalent circuit model of designed antenna.

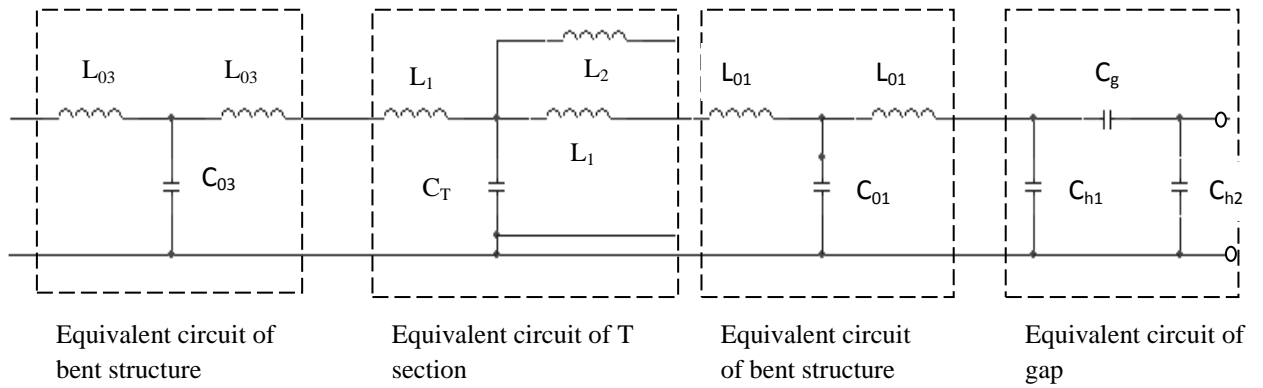


Figure 3.13 Equivalent circuit of Section I.

The overall equivalent structure helps us to derive the mathematical calculation of transfer function of the filter and show how the filter at some frequencies rejects them. Table 3.1 shows the calculated values of inductance and capacitance of equivalent circuit model of proposed antenna. These values are calculated by using various design equations that are presented above in the chapter.

Table 3.1 Parametric values of equivalent circuit model of proposed antenna.

Equivalent parameters	C_g (mF)	C_{h1} (pF)	C_{h1} (pF)	L_{01} (nH)	C_{01} (pF)	L_{03} (nH)	C_{03} (pF)
Parametric Values	0.345	0.759	0.53	0.1149	0.0078	0.1149	0.0078

CHAPTER 4

A NOTCH RECONFIGURABLE UWB ANTENNA DESIGN

4.1 INTRODUCTION

Presently there is uplifted enthusiasm for UWB technology in wireless communication because of its features of low power spectral density, low cost and energy efficiency. Firstly we designed basic UWB circular patch antenna with partial ground.

Next, we designed a reconfigurable antenna taking consideration of basic UWB structure. Two reconfigurable E to C shaped structure was placed beside the feedline of circular radiating patch.

Reconfigurability was achieved by placing RF switches at appropriate location and by varying the states of RF switches two antennas were incorporated in a single antenna.

Various parameters were studied and compared to reach best results, lengths of resonating structure plays a vital role in shifting the center frequency of notch band.

4.2 UWB CIRCULAR PATCH ANTENNA DESIGN

This antenna design is the base for our proposed antenna. It contains a circular patch of radius 8.6 mm and microstrip feedline of width 1.4 mm [17]. This structure is mounted on FR4 substrate with relative permittivity $\epsilon_r = 4.4$ of height 1.6 mm and height of the copper above substrate is 0.035 mm. This antenna design consists of partial ground plane over which FR4 substrate material and circular patch is placed. The basic circular UWB antenna design front and back side are shown in the figure 4.1.

The purpose of using partial ground is to increase bandwidth and better impedance matching [18]. Compared result of partial ground and normal ground plane is studied using CST software and shown in the figure 4.4. It is clear from the return loss curve that partial ground gives higher bandwidth and better impedance matching. The dimensions of partial ground are $30 \times 11 \text{ mm}^2$. The dimensions of basic circular UWB antenna design are; $L_s = 30 \text{ mm}$, $W_s = 30 \text{ mm}$, $W_f = 1.4 \text{ mm}$, $L_f = 11.9 \text{ mm}$, $L_g = 11 \text{ mm}$. The whole dimension of FR4 substrate is $30 \times 30 \times 1.6 \text{ mm}^3$.

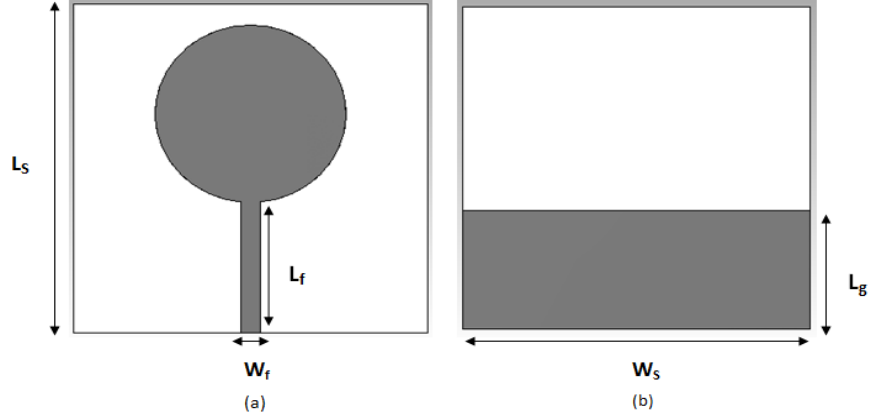


Figure 4.1 Circular UWB antenna design (a) front view and (b) back view.

The equivalent circuit of simple circular patch is presented as parallel R_1 , L_1 , C_1 circuit as shown in figure 4.2 and has input impedance Z_p . The expression for R_1 , L_1 , C_1 are shown below

$$C_1 = \frac{\pi r^2 \epsilon_0 \epsilon_r}{2h} \cos^2\left(\frac{\pi X_0}{L}\right) \quad (4.1)$$

$$R_1 = \frac{Q}{\omega_r C_1} \quad (4.2)$$

$$L_1 = \frac{1}{C_1 \omega_R^2} \quad (4.3)$$

Quality factor,

$$Q = \frac{C\sqrt{\epsilon_r}}{4fh} \quad (4.4)$$

where

L - Length of circular patch,

w - Width of circular patch,

h - Thickness of the substrate material,

X_0 - x coordinates of feed point, i.e., $X_0=L_f$,

ϵ_e - effective permittivity of the medium.

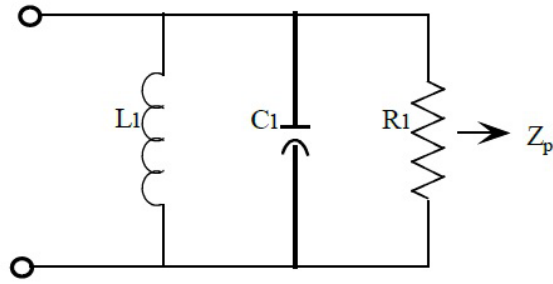


Figure 4.2 Equivalent circuit of circular patch [1].

After simulating antenna design in Computer Simulation Technology (CST) software antenna parameters were examined. Antenna parameters include return loss which is the reflected power due to scattering or reflection. Numerically return loss is given by

$$RL = -20 \log_{10} \left(\frac{P_i}{P_r} \right) \quad (4.5)$$

where P_i is the incident power

P_r is the reflected power

Return loss or S11 is measured in dB and if $S_{11} = 0$ dB that means no power is reflected back or all incident power is transmitted [1]. The simulated return loss of circular UWB antenna design is shown in figure 4.3. The figure shows the return loss is less -10 dB for the range of 3.2 to 13 GHz with fractional bandwidth of 120.9 %.

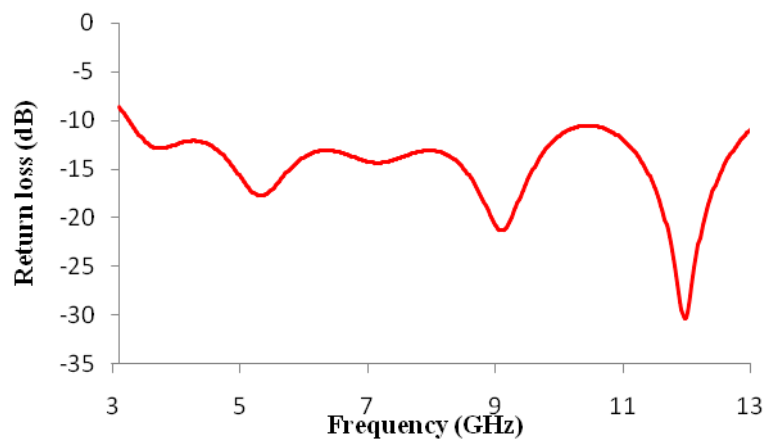


Figure 4.3 Simulated return loss curve of Circular UWB antenna design.

The parametric study is done for length of the ground and it is varied from 11 mm to 30 mm. Figure 4.3 presents the parametric study of length of the ground. When length is increased to maximum length as the length of the substrate, return loss is greater than -10 dB from 3.1 GHz to 8.8 GHz. When length is varied to 22 mm return loss is less than -10 dB for a small range. Decreasing the length further to 11 mm creates return loss which is less than -10 dB for the range from 3.2 to 13 GHz which is used for UWB technology.

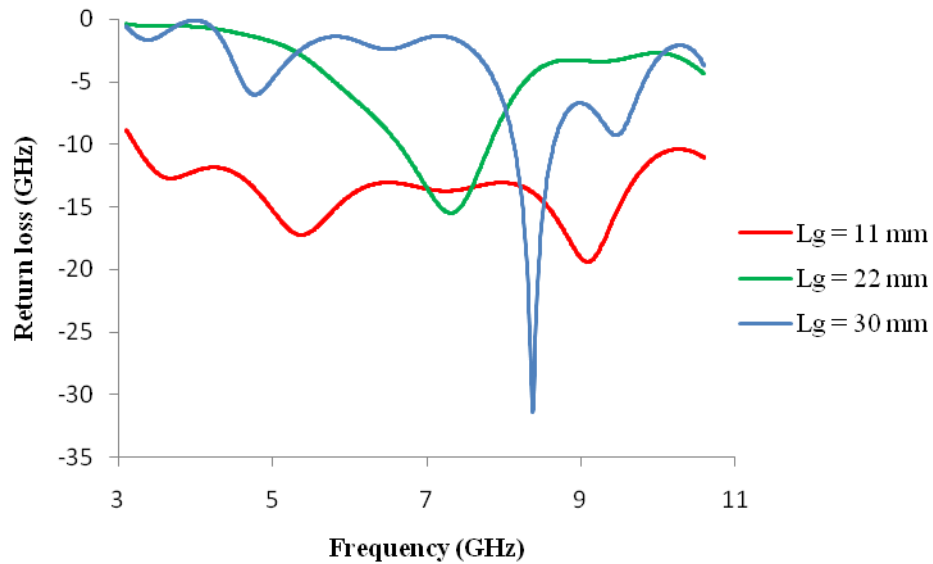


Figure 4.4 Parametric study of ground's length L_g .

4.3 UWB NOTCH ANTENNA DESIGN

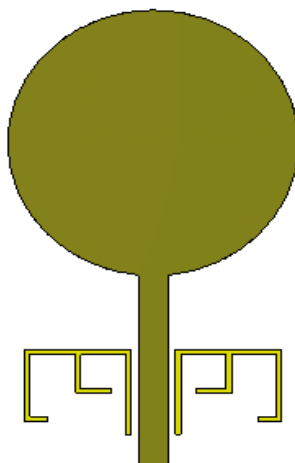


Figure 4.5 UWB notch antenna.

First step was to design a UWB antenna and the second step is to design antenna with band notch characteristics [19-28]. In the proposed antenna two resonators are etched beside the microstrip

feedline with a 0.15 mm gap between them. The two resonators act as stop band filter which filter out frequencies and create notch band. The dimensions of E shaped resonator are shown in the table 4.1.

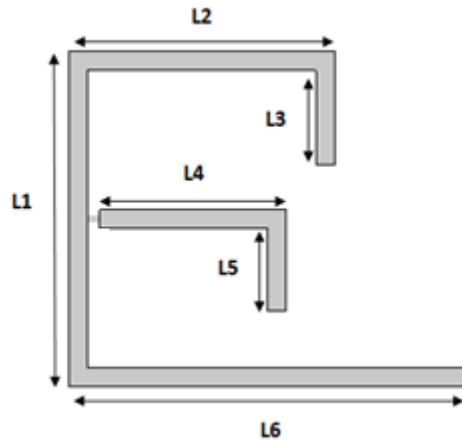


Figure 4.6 Labeled view of E shaped resonator.

The resonator's dimensions (length and width) act as inductance, and the gaps between the resonators and the circular patch feedline act as capacitance. The couplings of the resonators and circular patch feedline act as stopband filter at a certain frequency [53]. The lengths of the resonator significantly affect the notched frequency. That is, increase in the lengths of the resonator, shifts the notch bands in the direction of lower frequency, as inductance and capacitance effects are reduced. The notch frequency is stated here

$$f_{notch} = \frac{c}{2L\sqrt{\epsilon_{eff}}} \quad (4.6)$$

where ϵ_{eff} , L , c are the effective dielectric constant, the total length of the resonator and the speed of light in space, respectively [15].

Table 4.1 Dimensions of resonating structure shown in figure 4.6.

Parameters	Dimensions (mm)
L1	5.6
L2	4.1
L3	1.3
L4	1.8
L5	2
L6	4.8

4.4 PARAMETRIC STUDY

Parametric study is required to examine the antenna characteristics and it also help in finding the optimized results. In this research work parametric analysis is done for length and width of resonator structures. Middle frequency of the notch band can be managed by varying the lengths of resonator. By increasing or decreasing the width of the resonator leads to shift of the band to lower and upper frequency. Here we present parametric study of UWB antenna with E shaped structures placed on either side of circular patch feedline. Return loss curve of different lengths of resonator structure is depicted in the figure 4.7(a-e) when switch is closed. It is clear from the figure that notch band can be controlled according to the requirement of rejecting the interfering bands.

4.4.1 Parametric study of length L1 of the E shaped resonator

The optimum value of length L1 is 5.5 mm which is obtained by varying it to 4.5 mm and 6.5 mm. Increasing length to 6.5 mm creates notch band of 3.7 to 5.6 GHz and 7.2 to 9.7 GHz and decreasing L1 to 4.5 mm creates band notch of 4.2 to 6.5 GHz and 8 to 9.8 GHz. Whereas optimum value of L1 gets notch band of 4 to 6.2 GHz and 7.6 to 10 GHz with a VSWR of 20 in the first notch which is better than other VSWR's of other dimension. The compared results are compared in the figure 4.7.

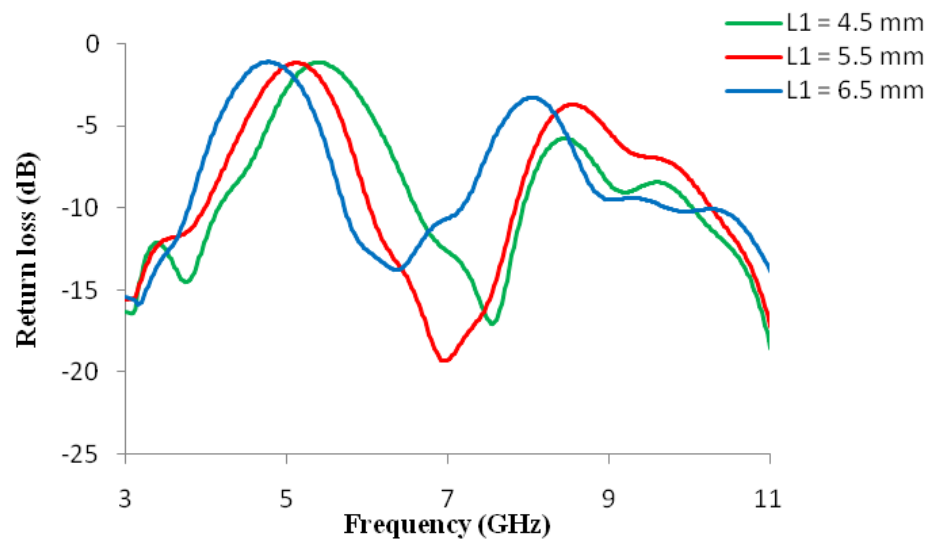


Figure 4.7 Simulated return loss with variations in length of resonator structure parameters length L1.

4.4.2 Parametric study of length L2 of the E shaped resonator

The optimum value of length L2 is 4 mm which is obtained by varying it to 3 mm and 5 mm. Increasing length to 5 mm creates notch band of 3.68 to 5.5 GHz and 7.6 to 10 GHz and decreasing L2 to 3 mm creates band notch of 4.1 to 6.6 GHz and 8.2 to 10.3 GHz. Whereas optimum value of L2

gets notch band of 4 to 6.2 GHz and 7.6 to 10 GHz. The compared results are compared in the figure 4.8.

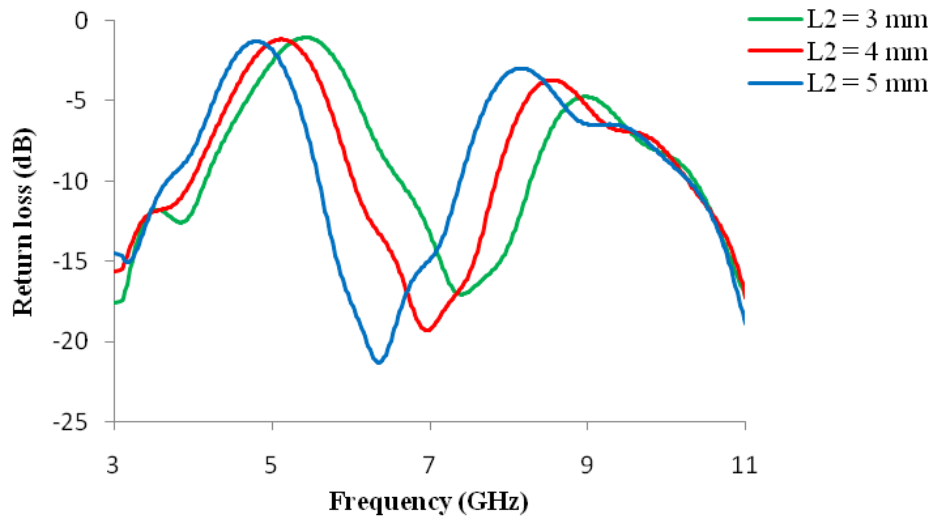


Figure 4.8 Simulated return loss with variations in length of resonator structure parameters length L2.

4.4.3 Parametric study of length L3 of the E shaped resonator

The optimum value of length L1 is 1.6 mm which is obtained by varying it to 0.6 mm and 2.6 mm. Increasing length to 2.6 mm creates notch band of 3.9 to 5.9 GHz and 7.5 to 10.1 GHz and decreasing L1 to 0.6 mm creates band notch of 3.68 to 5.5 GHz and second band to 7.4 to 10.28 GHz. Whereas optimum value of L1 gets notch band of 4 to 6.2 GHz and 7.6 to 10 GHz. The compared results are compared in the figure 4.9.

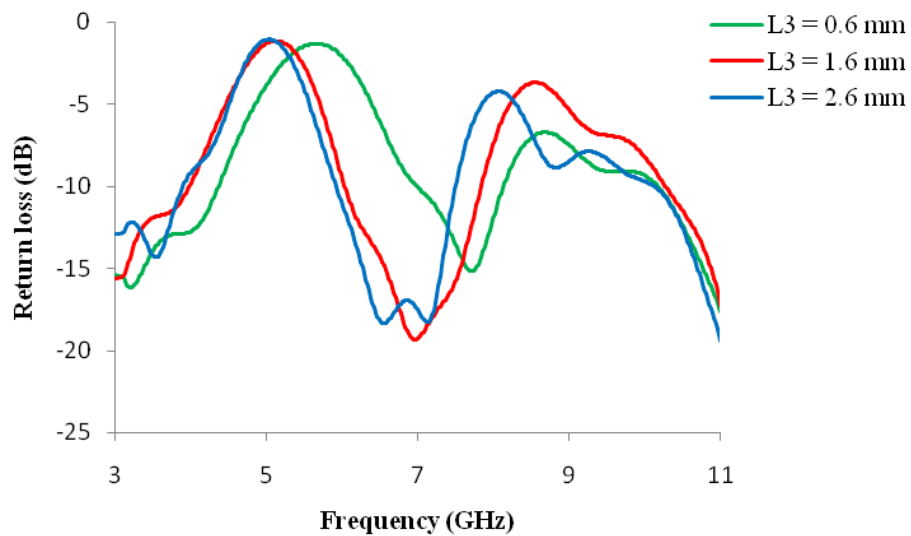


Figure 4.9 Simulated return loss with variations in length of resonator structure parameters length L3.

4.4.4 Parametric study of length L4 of the E shaped resonator

The optimum value of length L4 is 1.8 mm which is obtained by varying it to 0.8 mm and 2.8 mm. Increasing and decreasing the length to 2.8 mm and 0.8 respectively creates same notch band of 4.3 to 6.6 GHz. The compared results are compared in the figure 4.10.

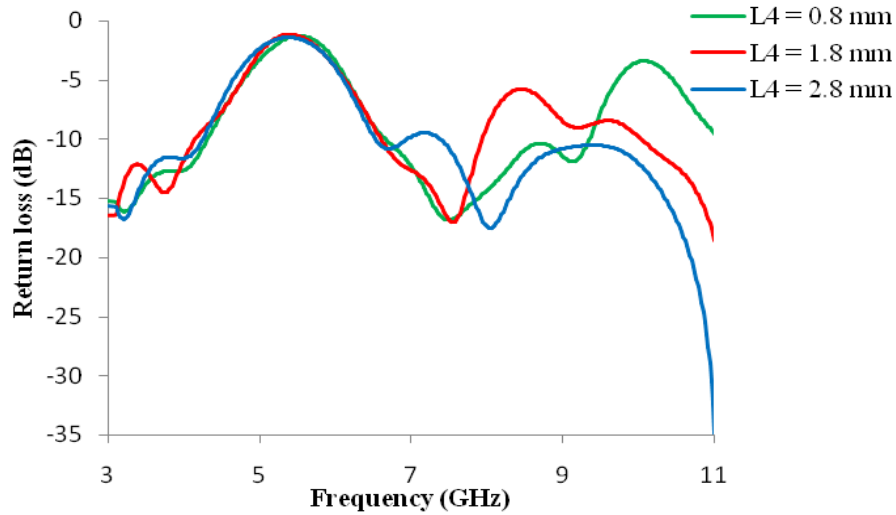


Figure 4.10 Simulated return loss with variations in length of resonator structure parameters length L4.

4.4.5 Parametric study of length L5 of the E shaped resonator

The optimum value of L5 is 1 mm and by varying the lengths from 0.5 mm to 2 mm the first notch band is observed to be same as 4 to 6.2 GHz. Second notch band is shifted to 9.4 GHz onwards and 10 GHz onwards when length is decreased to 0.5 mm and increased to 2 mm. The compared results are compared in the figure 4.11.

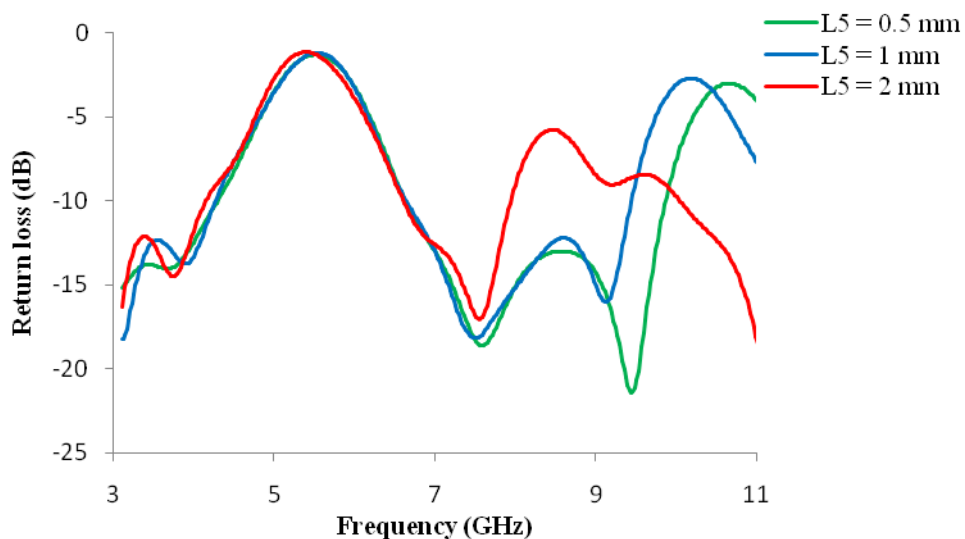


Figure 4.11 Simulated return loss with variations in length of resonator structure parameters length L5.

4.4.6 Parametric study of length L6 of the E shaped resonator

The optimum value of L6 is 4.8 mm and by varying the lengths from 3.8 mm to 5.8 mm the first notch band is observed to be same as 4 to 6.2 GHz. By decreasing length L6 to 3.8mm shifts the lower notch band to 3.9 – 6.2 GHz and by increasing L6 length to 5.8mm shifts the lower notch band to 3.8 – 5.8 GHz. The compared results are compared in the figure 4.12.

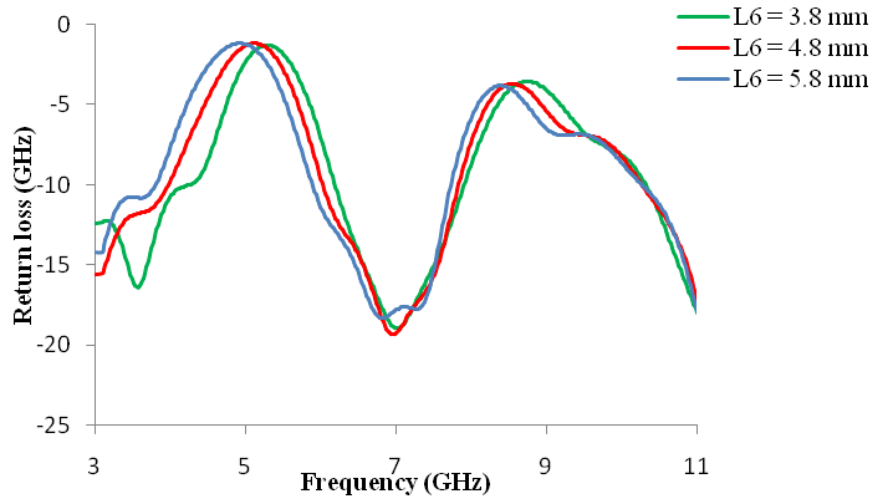


Figure 4.12 Simulated return loss with variations in length of resonator structure parameters length L6.

4.4.7 Parametric study of length W of the E shaped resonator

Next parameter that is varied is the width of the resonating structure when switch is ON. It is clear from the figure 4.13 that varying width of resonating structure does not affect antenna parameters; there is slight shift of notch band towards lower frequency when width of the resonating structure is increased.

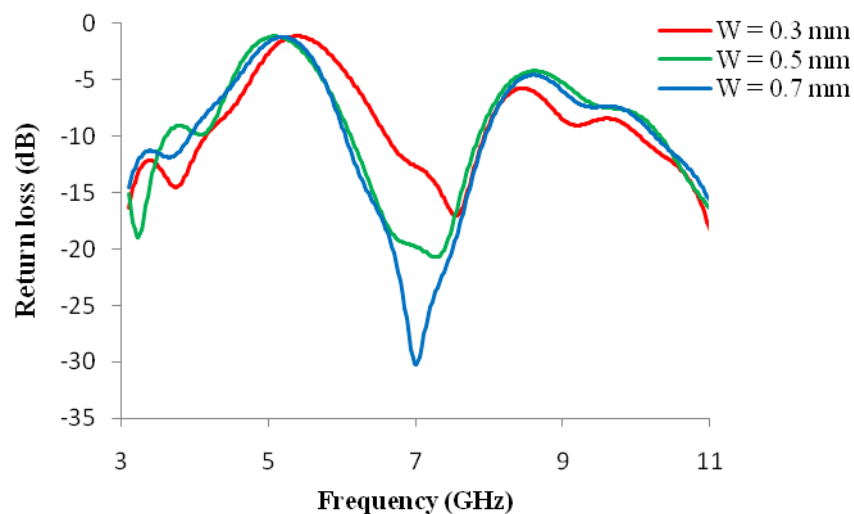


Figure 4.13 Simulated return loss with variations in width W of resonating structure.

4.5 RECONFIGURABLE NOTCH UWB ANTENNA DESIGN

UWB antenna is made notch reconfigurable by using RF switches in the E shaped parasitic element. The proposed antenna comprises of two reconfigurable E to C shaped resonator and it is depicted in the figure 4.14.

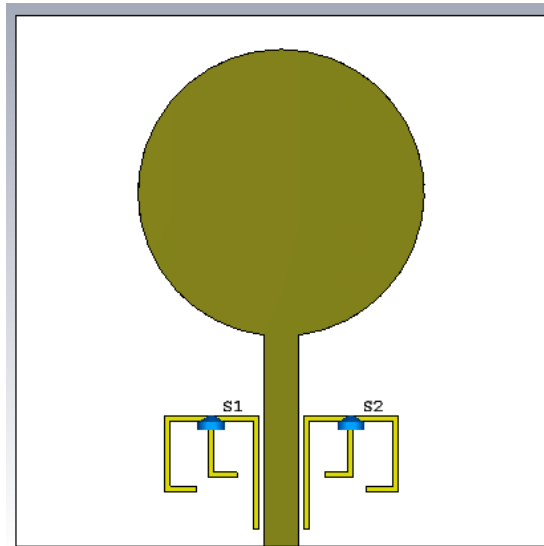


Figure 4.14 Front view of the reconfigurable UWB antenna.

The back part is similar to the base antenna which contains partial ground with dimension $30 \times 11 \text{ mm}^2$. The closure view of the resonators is shown in the figure 4.15 given below. When switch is on the resonator shape is like letter E and when switch is in off state it reconfigures resonator shape to letter C. The dimensions of E and C shaped resonator are optimized as shown in the figure 4.15 and there optimize values are shown below in the table 4.1.

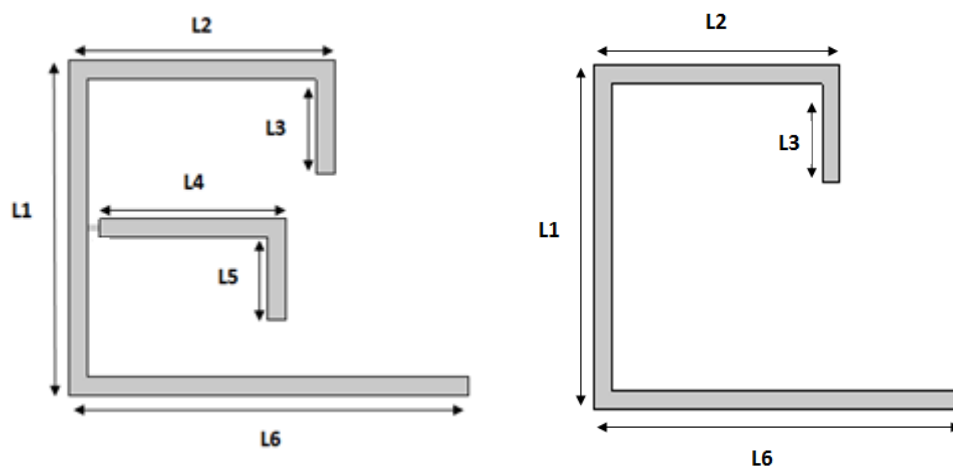


Figure 4.15 Closure view of E shaped and C shaped resonator.

For achieving reconfiguration there are few techniques one is by using different type of switches for example PIN diodes, varactor diodes, SPST, SPDT, SP4T switches and other way is by mechanically moving antenna structure using motor. We are using two SPST switches AMT2551011 because these switches have high isolation, low insertion loss, broad bandwidth from DC to 18 GHz and fast switching [16].

Biasing of RF switches gives four different states and different shape configuration beside the feedline of radiating patch. Table 4.2 explains different configurations of resonators when switches are in different states. When both switches are ‘ON’, E shape resonators are configured along the feedline. Simulated return loss is shown in the figure 4.16 and two notch bands are created. When one switch is ‘ON’ and other is ‘OFF’, one E shape resonator and one C shape resonator are reconfigured. Simulated results for two cases when one switch is ‘ON’ and other is ‘OFF’ or vice-versa are same and shown in the figure 4.17. When both switches are ‘OFF’, two symmetric C shaped resonators are reconfigured beside the feedline of circular patch. Simulated return loss when switches are ‘OFF’ is shown in figure 4.18.

Table 4.2 Different RF switching states and resonators shape.

RF Switching states		Resonators configuration	
Switch 1	Switch 2	Shape of Resonator 1	Shape of Resonator 2
OFF	OFF	Modified C shape	Modified C Shape
OFF	ON	Modified C shape	Modified E shape
ON	OFF	Modified E shape	Modified C shape
ON	ON	Modified E shape	Modified E shape

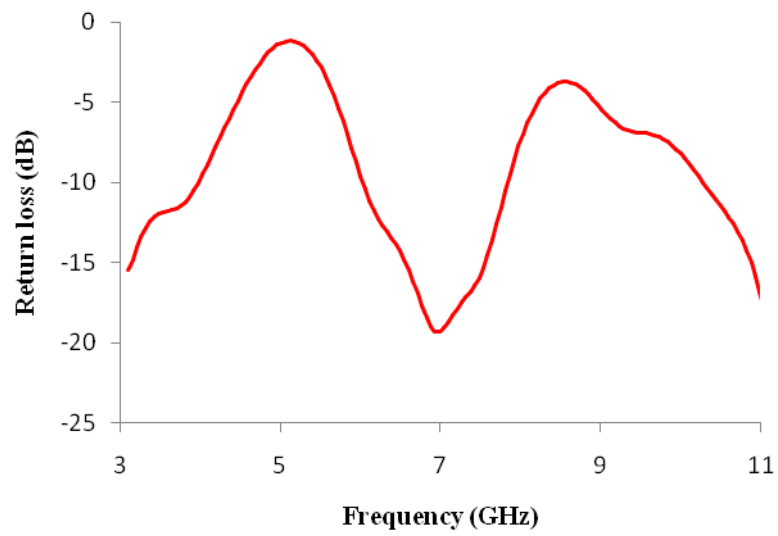


Figure 4.16 Simulated return loss when both switches are 'ON'.

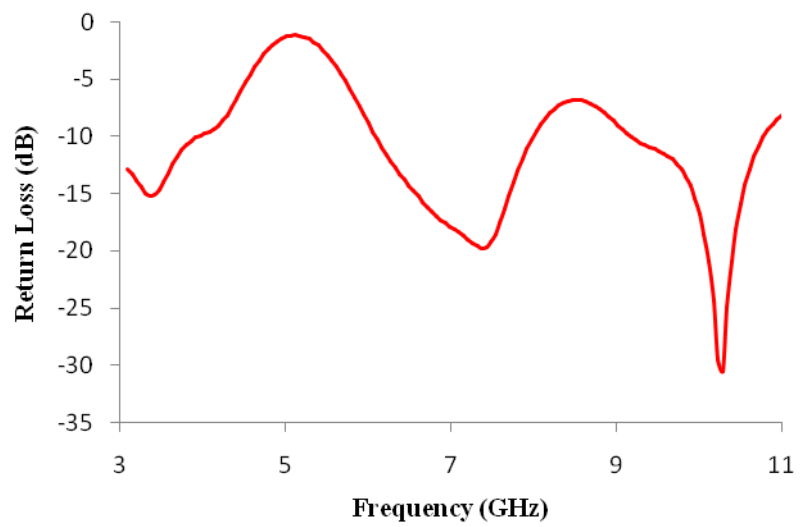


Figure 4.17 Simulated return loss when one switch is 'ON' and other is 'OFF'.

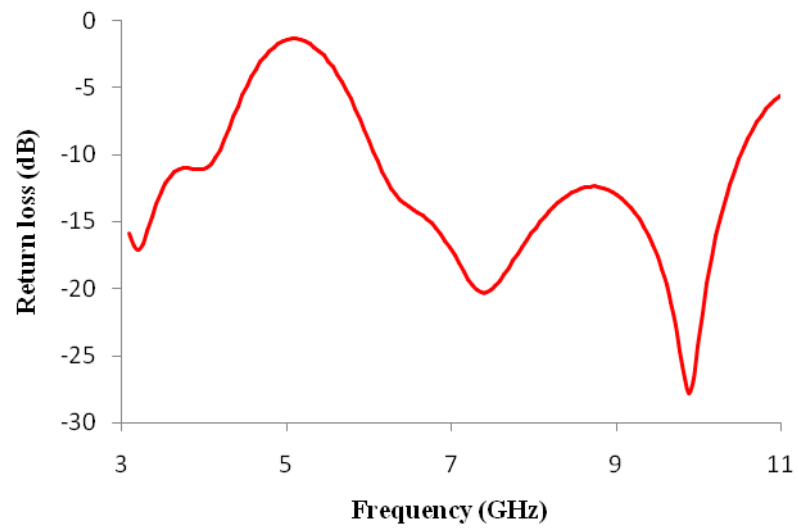


Figure 4.18 Simulated return loss when both switches are 'OFF'.

CHAPTER 5

FABRICATION AND TESTING

5.1 INTRODUCTION

In this chapter the simulated and measured results of the fabricated antenna are represented. For simulated results we have used CST Suite 2016. After the antenna fabrication results are measured on KEYSIGHT E5063A vector network analyzer. Figure 5.1 and 5.2 shows the top view and bottom view of the notch reconfigurable UWB antenna design respectively, the fabricated antenna is made up of PEC copper of height 0.035 with FR4 substrate of height 1.6 mm. We have here discussed about the return loss, gain, VSWR of the proposed antenna.

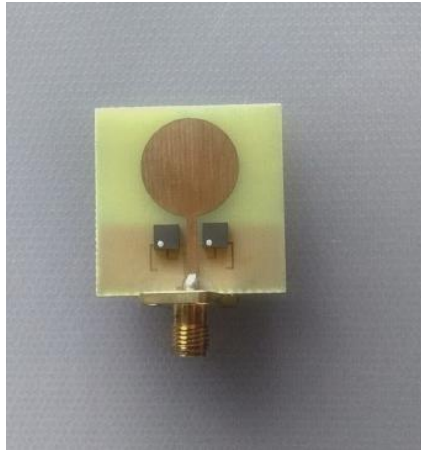


Figure 5.1 Picture of fabricated antenna.

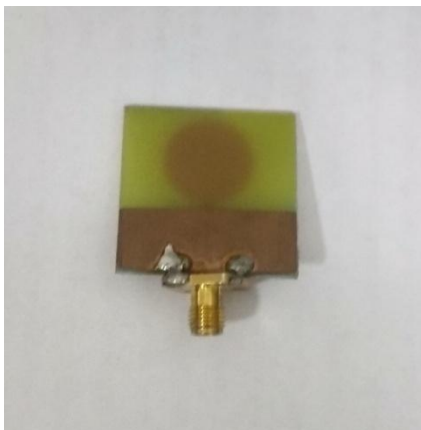


Figure 5.2 Picture of back side of fabricated antenna.

5.2 RESULTS AND DISCUSSION

Both measured and simulated return loss results are shown in the figure 5.3 when both the RF switches are OFF and C shape structures are placed beside the circular patch feedline. Single notch band is obtained in this condition and in the measured result notch band is from 3.9 to 5.7 GHz as shown in the figure 5.3. Application of the proposed antenna when switches are OFF is that it covers UWB range and rejects WLAN, WiMAX, C-band and Satellite X band.

When one of the RF switches is ON and other is OFF the resonating structures reconfigured to C shape and E shape and corresponding measured and simulated results are displayed in the figure 5.4. Dual notch band 3.9 to 5.7 GHz and 7.7 to 9.1 GHz are reconfigured in the given state of switches. The measured two notch bands are 4.1 GHz – 5.8 GHz and 8.4 GHz – 10.7 GHz as shown in the figure 5.4. Application of the proposed antenna when one switch is ON and other is OFF is that it covers UWB range and rejects WLAN, WiMAX, C-band and meteorological satellites.

When both RF switches are in ON state; E shaped resonators are reconfigured on both sides of the feedline. Because of E shaped resonators on each side of microstrip feedline the notch bands; 4 to 6.2 GHz and 7.6 to 10 GHz are obtained and measured notch bands are 4.2 GHz – 5.8 GHz and 7.8 GHz – 9.85 GHz as shown in the figure 5.5. Application of the proposed antenna when switches are OFF is that it covers UWB range and rejects WLAN and WiMAX. Table 5.1 explains the antenna operations for different state of switches.

Table 5.1: Antenna operation for different states of switches.

Antenna operations	Switch states
UWB coverage with dual notch band in WLAN, WiMAX, C-band and Satellite X band.	S1 and S2 both are on
UWB coverage with dual notch band in WLAN, WiMAX, C-band and meteorological satellites.	S1 is ON and S2 is OFF
UWB coverage with single notch band in WiMAX, WLAN Band	S1 and S2 both are off

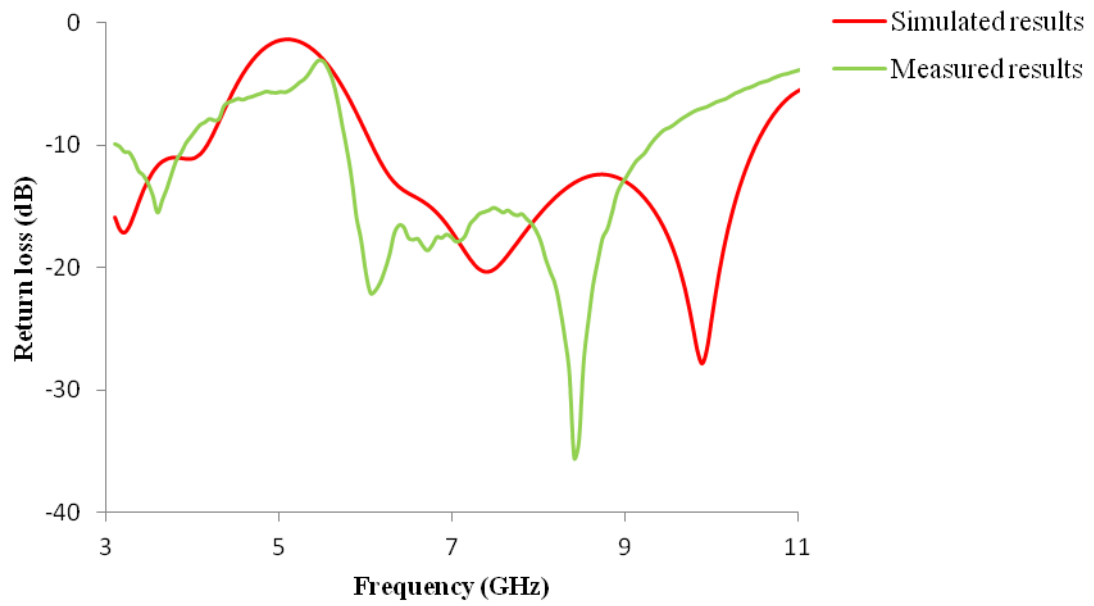


Figure 5.3 Simulated and measured results of frequency reconfigurable antenna when RF switches are OFF.

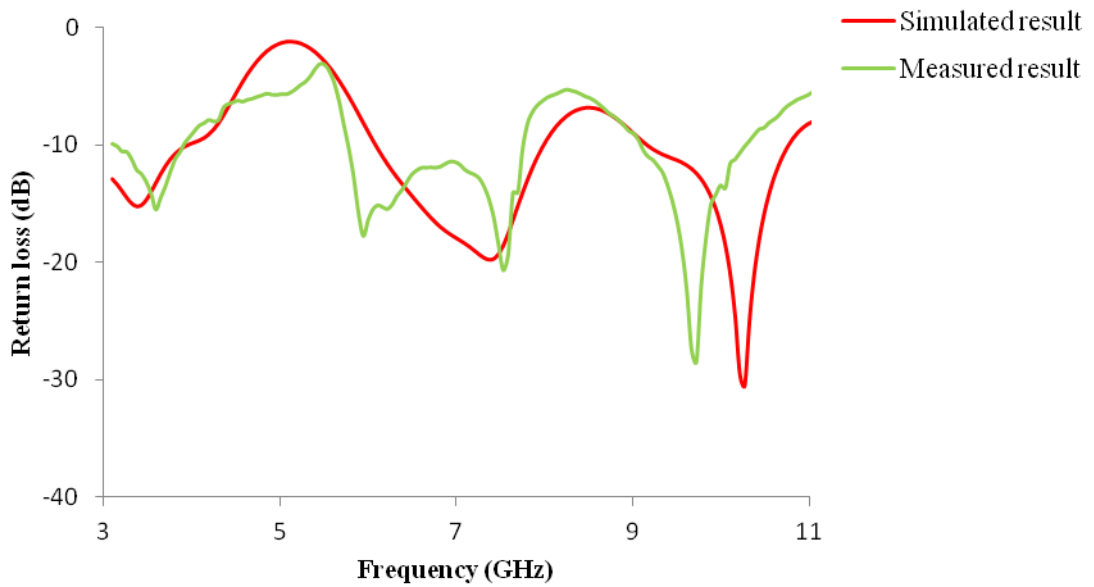


Figure 5.4 Simulated and measured results of frequency reconfigurable antenna when one of the RF switches is ON and other is OFF.

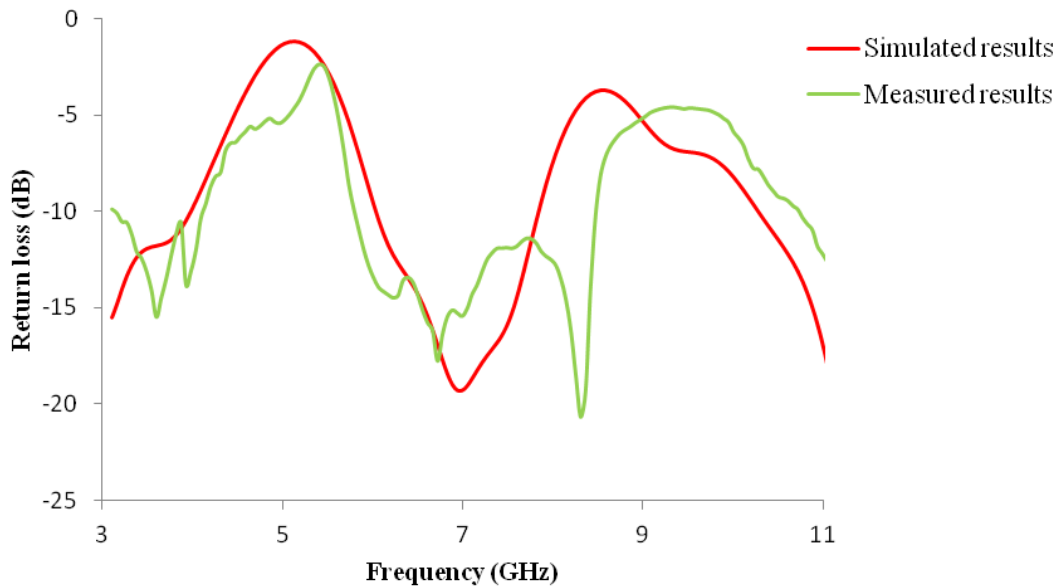


Figure 5.5 Simulated and measured results of frequency reconfigurable antenna when both RF switches are ON.

Surface current distribution is another important result that explains the phenomenon of how interfering frequencies are eliminated from the ultra wide band. Surface current distribution in the proposed antenna is shown in the figure 5.6 when switches are OFF, a closure view of resonating structure and feedline is represented in this figure. The surface current distribution at 5.1GHz is mainly concentrated around the resonating structures and the current flow is mainly dominant around resonating structures. Also the current flows in opposite directions in feedline and resonating structures which lead to attenuation at the frequency band of 4 to 6.2GHz. Similarly this surface current phenomenon works when switches are in ON state at frequency 5.1 GHz and 8.5GHz which lead to attenuation of 7.6 to 10 GHz band along with 4 to 6.2 band, this is shown in the figure 5.7(a-b). In this condition of ON switches now current flow in the adjoining structure in addition to C structure and it is denser at high frequencies.

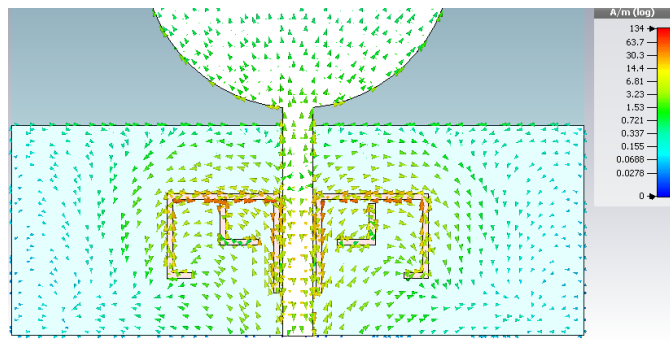


Figure 5.6 Simulated surface current distributions for proposed reconfigurable C shaped antenna at the notch frequency 5.1 GHz.

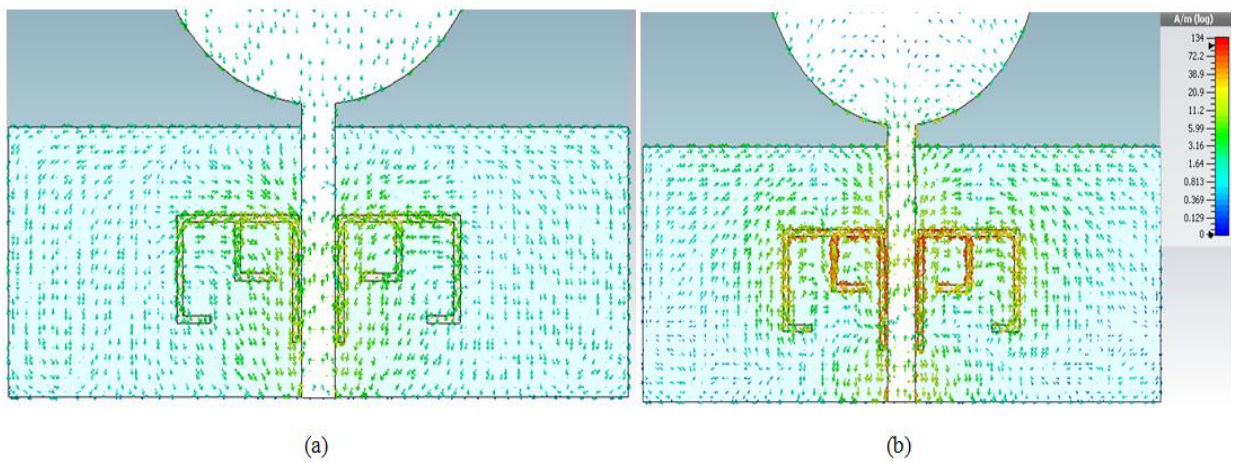


Figure 5.7 Simulated surface current distributions for proposed reconfigurable E shaped antenna at the notch frequencies (a) 5.1 GHz and (b) 8.5 GHz.

Gain of the proposed antenna is compared and shown in the figure 4.13 for all states of switches and the initial antenna design. Antenna gain describes how much power is directed (transmitted) towards peak radiation to that of an isotropic source. For our proposed antenna gain varies between 2 to 5.5 dB at different operating frequencies. VSWR is the antenna parameter that describes how well the antenna is impedance matched with the corresponding transmission line. VSWR of the reconfigurable UWB antenna in different switch states and VSWR of the basic UWB antenna design are shown in the figure 5.8. The reconfigurable antenna VSWR is highest that show good rejection in the band 4 – 6.2 GHz. Figure 5.9 shows the VSWR of proposed antenna and initial UWB antenna design.

Figure 5.10 shows the E plane and H plane radiation pattern of the proposed antenna when RF switches are OFF at 3.2 GHz, 7.3 GHz and 9.8 GHz. Figure 5.11 shows the E plane and H plane radiation pattern of the proposed antenna when RF switches are ON at 5.1 GHz, 6.8 GHz and 8.4 GHz. It is clear from the figures that H plane for both states have omni directional radiation pattern.

The E plane radiation patterns when switches are off have more radiations in one direction and the E plane radiation pattern when switches are on are cardioid shaped.

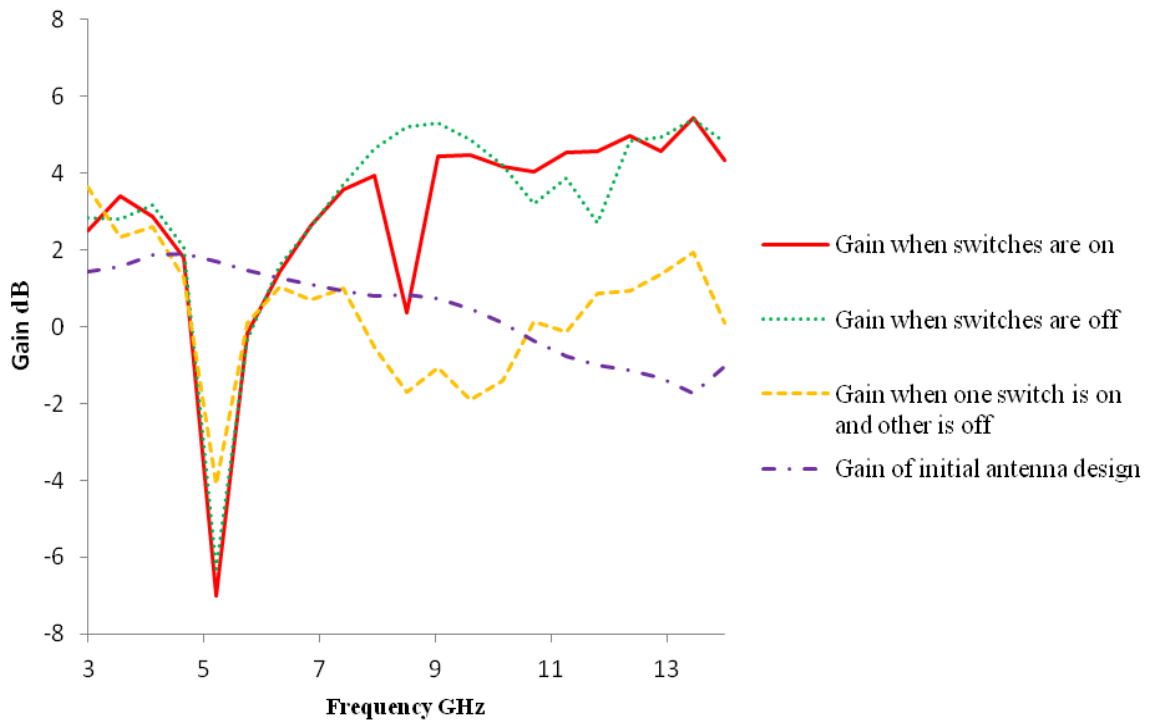


Figure 5.8 Simulated maximum gain comparison of single band notch and dual band notch when switches are off and on respectively.

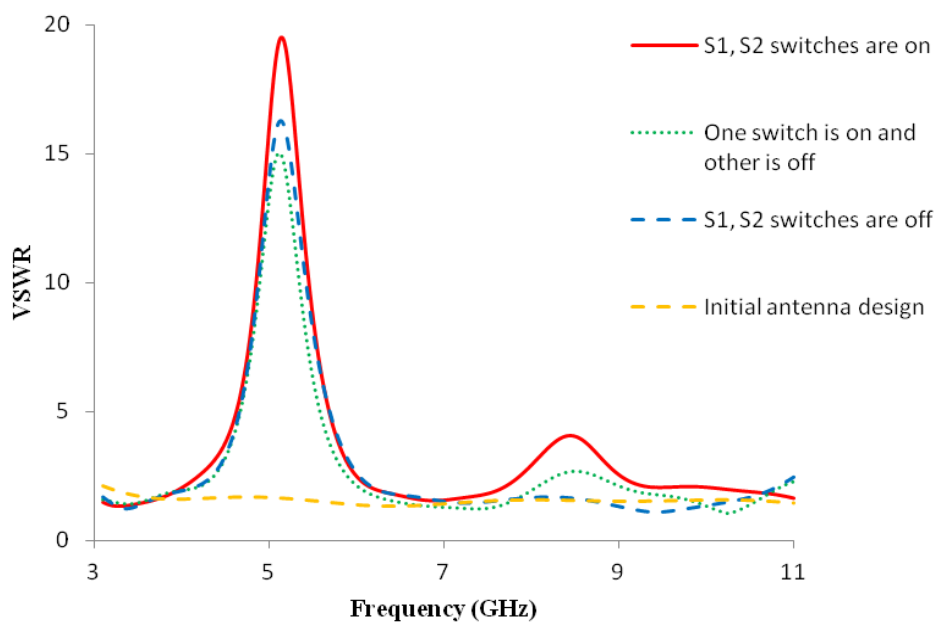
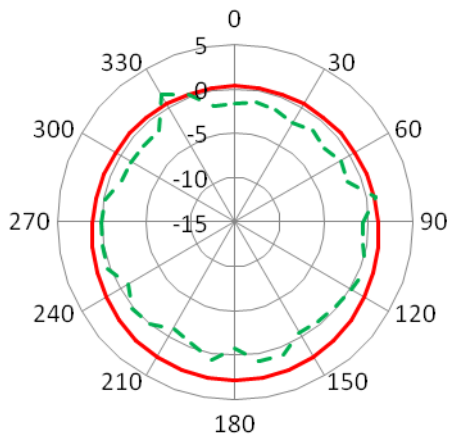
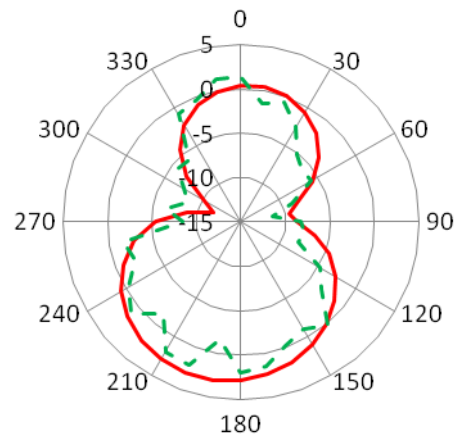


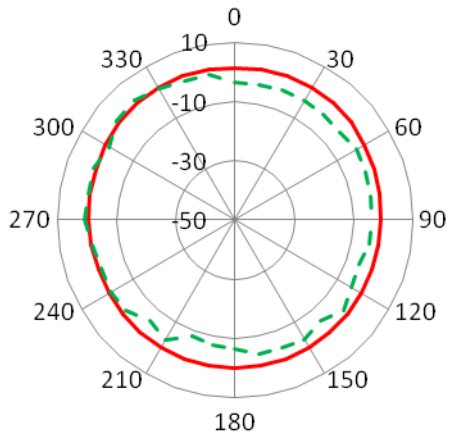
Figure 5.9 Comparison of simulated VSWR when switches are on and off.



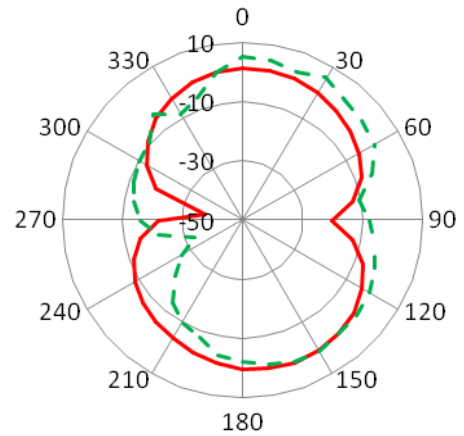
H plane at 3.2 GHz



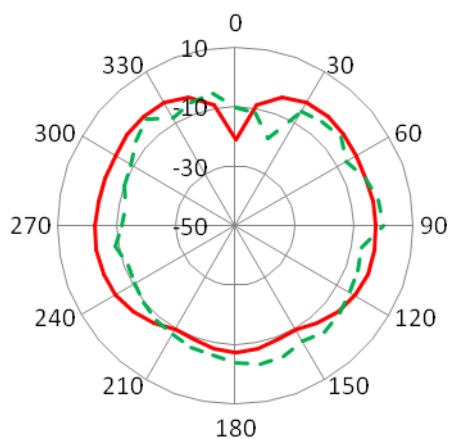
E plane at 3.2 GHz



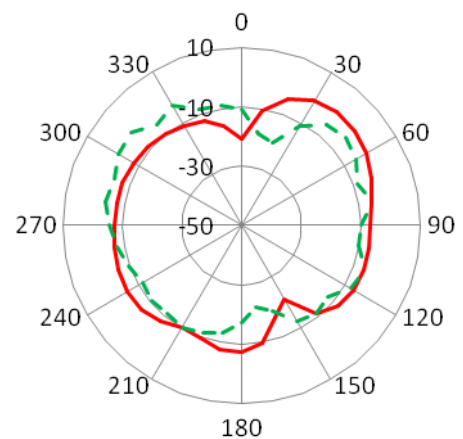
H plane at 7.3 GHz



E plane at 7.3 GHz

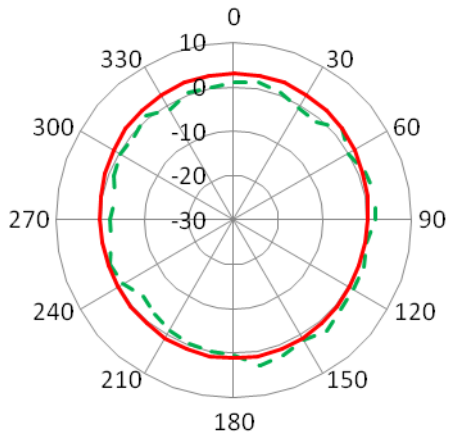


H plane at 9.8 GHz

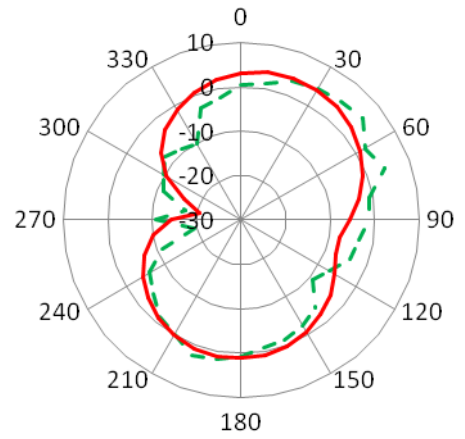


E plane at 9.8 GHz

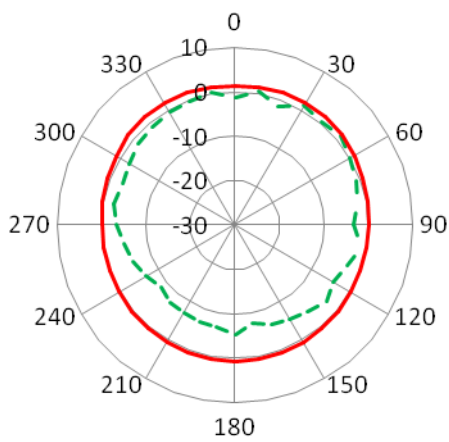
Figure 5.10 ——— Measured and - - - - simulated results of radiation pattern of E, H plane when switches are OFF at frequencies 3.2 GHz, 7.3 GHz and 9.8 GHz.



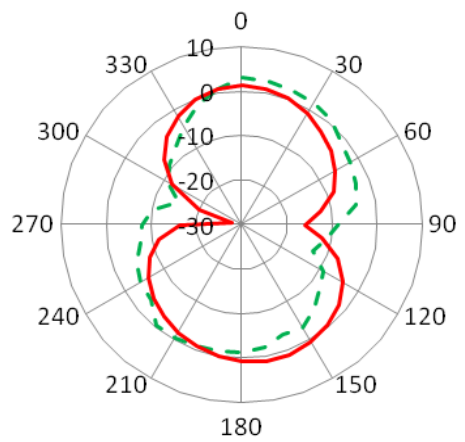
H plane at 5.1 GHz



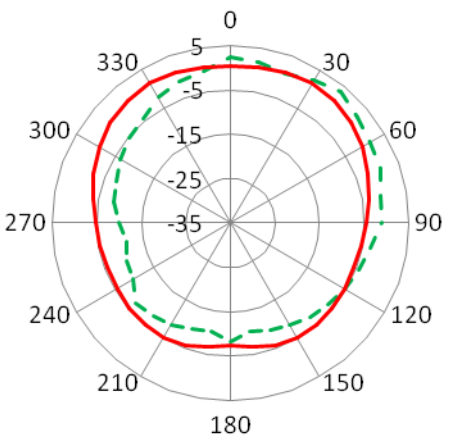
E plane at 5.1 GHz



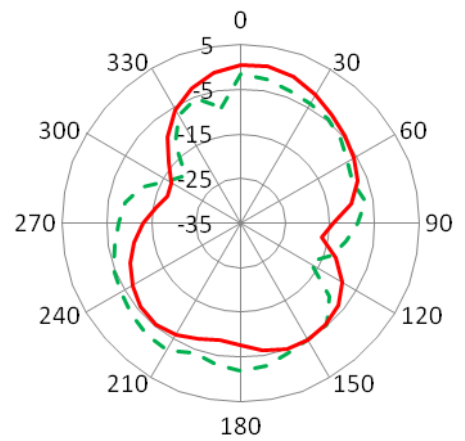
H plane at 6.8 GHz



E plane at 6.8 GHz



H plane at 8.4 GHz



E plane at 8.4 GHz

Figure 5.11 ——— Measured and - - - - simulated results of radiation pattern of E, H plane when switches are ON at frequencies 5.1 GHz, 6.8 GHz and 8.4 GHz.

CHAPTER 6

CONCLUSION

In this thesis we have designed a circular patch UWB antenna and further modified this antenna by placing two symmetrical resonators E and C shaped beside feedline to attain band notch characteristics. This technique is placing parasitic elements near the radiating patch for achieving band notch characteristics.

After obtaining a notch band UWB antenna, a frequency reconfigurable antenna is designed. Reconfigurability is achieved by employing RF switch in correct location which connects two parasitic elements and reconfigures one shape into another that is reconfigures E shape to C shape or vice-versa.

One single frequency reconfigurable antenna has two antenna characteristics. One antenna that is configured has capability to reject interferences from WLAN, WiMAX and C band spectrum. Second antenna is reconfigured when resonator shape changes to E shape from C shape and it has capability to reject interferences from WLAN, WiMAX, C band spectrum and X band satellite communication. The simulated and measured results have good agreement and measured radiation pattern represent that proposed antenna has omnidirectional characteristics in the H plane. Gain varies between 2 to 5.5 dB at different operating frequencies and is good for practical application. The structure has been analyzed for the two states of the switches which tune notch bands. By varying the parameters of reconfigurable modified C and E shaped structure, the middle frequencies of the rejected bands can be changed.

UWB technology has various applications in high data rate transmissions, military purpose, indoor applications and many more. Reconfigurable antenna can enhance the application of UWB technology and incorporate various applications together in one single antenna.

New techniques can be used to optimize reconfigurable antenna characteristics in future. Smart materials and hybrid antennas that include pattern, polarization and frequency reconfigurability can be used for better functionality and also helps in reducing the size of antennas.

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LIST OF PUBLICATIONS

Communicated

- Ritika Sharma, Rajesh Khanna, " A Novel UWB Antenna with Reconfigurable Notch Bands," communicated to *International Journal of Microwave and Wireless Technologies* on 7, July 2018.