

**Rejection of Quadruple Interfering Bands in UWB Antenna by Using  
Stub Loaded SIRs**

Thesis submitted towards the partial fulfillment of requirement for the

award of degree of

**Master of Engineering**

**In**

**Wireless and Communication Engineering**

Submitted by

**Jyotsna Kapoor**

**Roll No. 801263012**

Under the guidance of

**Dr. Rajesh Khanna**

**Professor, ECED**

**T.U. Patiala**



**ELECTRONICS AND COMMUNICATION ENGINEERING  
DEPARTMENT**

**THAPAR UNIVERSITY**

**(Established under the section 3 of UGC Act, 1956)**

**PATIALA – 147004 (PUNJAB)**

**JUNE -2014**

## CERTIFICATE

I, **Jyotsna Kapoor** hereby declare that the work, which is being presented in this thesis entitled "**Rejection of Quadruple Interfering Bands in UWB Antenna by Using Stub Loaded SIRs**" by me in the partial fulfillment of the requirements for the award of degree of Masters of Engineering in Wireless and Communication at Thapar University, Patiala, is an authentic record of my work carried out under the guidance of **Dr. Rajesh Khanna**, Professor, Electronics and Communication Engineering Department, Thapar University, Patiala.

The matter presented in this thesis has not been submitted in any other University / Institute for the award of degree of Master of Engineering.

Date: 30/6/14

*Jyotsna Kapoor*  
Jyotsna Kapoor

Roll no. 801263012

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

Date: 30/6/14

*Rajesh Khanna*

**Dr. Rajesh Khanna**

Professor, ECED

Thapar University, Patiala

Countersigned by:

*Sanjay Sharma*  
**Dr. Sanjay Sharma**  
Professor & Head, ECED  
Thapar University, Patiala

*S. K. Mohapatra*  
**Dr. S. K. Mohapatra**  
Dean of Academic Affairs  
Thapar University, Patiala

## ACKNOWLEDGEMENT

Words are often too less to reveal one's deep regards. Results are not the outcome of the efforts of a single person. I would like to express my profound sense of gratitude and respect to all those who helped me directly or indirectly through this phase of my thesis work.

With deep sense of gratitude, I express my sincere thanks to my esteemed and worthy guide **Dr. Rajesh Khanna**, Professor, Electronics and Communication Engineering Department, Thapar University, Patiala, for his valuable advice, motivation, guidance, encouragement, efforts, timely help and the attitude with which he solved all of my queries regarding thesis work.

I would also like to thank **Dr. Kulbir Singh**, P.G. Coordinator and all the faculty members of ECED for their intellectual support and unyielding encouragement. I am deeply indebted to all my friends who helped me with their encouragement, ample morale support and valuable suggestions and contribution towards this phase of my thesis work.

Most importantly, I would like to thanks my parents and the almighty for showing me the right direction out of the blue, to help me stay calm in the oddest of the times and keep moving in all the situations.

**Jyotsna Kapoor**

## ABSTRACT

In today's era wireless is fastest growing segment of the communication field. Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) technologies are the most rapidly growing areas in the modern wireless communication. This actually provides users the mobility to move around within a broad coverage area and still be connected to the network. In today's environment, technology demands antennas which can operate on different wireless bands and should have different features like low cost, minimal weight, low profile antennas that are capable of maintaining high performance over a large spectrum of frequencies. In today's environment, technology demands ultra wideband antennas which can operate at wide range of frequencies at lower power level. But due to large number of narrow bands lying in this ultra wideband, there is interference in the one band due to other. So, there is requirement of efficient and a high performance antenna which operates at UWB but also rejects the interfering bands. In order to have transmission in frequency bands other than that of WLAN, WiMAX etc., it is important to reject these interfering bands at these frequencies bands are used in a wide range worldwide. Hence, there will be more interference in the transmission in these bands as compared to other frequency bands.

In this thesis report, different techniques for the removal of interfering bands in the UWB antenna are discussed. The work is done by installing different resonators on UWB antenna. First of all, the theory of wave cancellation is discussed. After this metamaterial properties are discussed. A SIR and circular SRR are used to reject 2.4, 3.5, and 5.8GHz frequencies along the feed line of UWB antenna. Results are verified on CST Studio 2010. Quadruple band rejection is done by using SIR, square SRR along feed line and CSRR on patch of antenna. Quadruple bands are 2.4GHz, 3.5GHz, 5.8GHz and 8.4GHz. This structure is also designed and simulated on CST 2010. Lastly a Quadruple band rejection is also done by using stub loaded SIRs along the feed line. Here bands are notched at the frequencies 2.4GHz, 3.5GHz, 5.8GHz and 7.5GHz. These stub loaded SIRs improve VSWR.

The wideband rejection antenna is then fabricated and tested using Roger 4350 substrate of thickness .802mm. The antenna is tested using Agilent VNA model no. N5222A. The measured results and simulated results are shown. The comparison between the simulated results and the measured results are also shown. The measured and simulated results obtained are similar to each other with a slight variation.

# TABLE OF CONTENT

CERTIFICATE	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iii
TABLE OF CONTENTS	iv
LIST OF FIGURES	vi
LIST OF TABLES	ix
LIST OF ABBREVIATIONS	x
<b>1. INTRODUCTION</b>	<b>1-3</b>
1.1 Overview	1
1.2 Ultra-Wideband Technology	1
1.3 UWB Advantages	1
1.4 UWB Importance	2
1.5 Drawbacks of UWB	2
1.6 Techniques used for Notching in UWB	2
1.7 Objective Of Thesis	2
1.8 Thesis Organization	3
<b>2. LITERATURE SURVEY</b>	<b>4-12</b>
2.1 Research Paper Literature Survey	4
2.2 Conclusion	12
<b>3. DIFFERENT TYPES OF RESONATORS FOR NOTCHING</b>	<b>13-25</b>
3.1 Stepped Impedance Resonator	13
3.1.1 Wave Cancellation Theory	14
3.1.2 Basic Structure and Mathematical Analysis of SIR	15
3.2 Metamaterial	16
3.2.1 Split Ring Resonator	18
3.2.1.1 Physics of SRR	19
3.2.1.2 Structure of Split Ring Resonator	20
3.2.1.3 Equivalent Circuit and Mathematical Analysis of SRR	20
3.2.2 Complimentary Split Ring Resonator	22
3.3 Stub Loaded Stepped Impedance Resonator	23

3.4 Conclusion	25
<b>4. NOTCHING OF UNDESIRED FREQUENCY BANDS BY DIFFERENT TYPES OF RESONATORS</b>	<b>26-41</b>
4.1 Principle of Operation for Implementing SIR along Feed Line	26
4.2 Principle of Operation for Implementing SRR and CSRR	27
4.3 Design Approach	27
4.4 Triple Notch Bands in UWB by Using SIR and Circular SRR	27
4.5 Quadruple Notch Bands in UWB by Using SIR, Square SRR and CSRR	34
4.6 Conclusion	41
<b>5. REJECTION OF QUADRUPLE UNDESIRED FREQUENCIES BY USE OF STUB LOADED SIRs</b>	<b>42-52</b>
5.1 Design of Ultra Wideband with Stub Loaded SIR	42
5.2 Fabricated Antenna with Stub Loaded SIRs	49
5.3 Testing Using VNA	50
5.4 Simulated Result	51
5.5 Conclusion	52
<b>6. CONCLUSION AND FUTURE WORK</b>	<b>53</b>
6.1 Conclusion	53
6.2 Future scope	53
<b>REFERENCES</b>	<b>54-57</b>
<b>LIST OF PUBLICATION</b>	<b>58</b>

## LIST OF FIGURES

Fig. 3.1	Basic Structure of SIR (i) $\lambda_g/4$ type, (ii) $\lambda_g/2$ type and (iii) $\lambda_g$ type	13
Fig. 3.2	Filters are Connected in Parallel	14
Fig. 3.3	Basic Stepped Impedance Resonator	15
Fig. 3.4	Equivalent Circuit of Stepped Impedance Resonator	15
Fig. 3.5	Classification of Material (DPS : double positive, ENG: epsilon negative, DNG: double negative, MNG: mu negative)	17
Fig. 3.6	The Diagrams of Electric Field, Magnetic Field, Wave Vector ( $E, H, k$ ) and Pointing Vector ( $S$ ) for Electromagnetic Wave Propagation in Right-handed and Left handed medium	18
Fig. 3.7	Split Ring Resonator	19
Fig. 3.8	Analogy of SRR with LC Circuit	19
Fig. 3.9	Square Split Ring Resonator	20
Fig. 3.10	Lumped Equivalent Circuit of SRR	21
Fig. 3.11	Complementary Split Ring Resonator	22
Fig. 3.12	Equivalent Circuit of CSRR	23
Fig. 3.13	(a) Configuration of the Proposed Shorted-Stub Loaded SIR, (b) Odd-mode Equivalent Model, (c) Even-mode Equivalent Model	23
Fig. 4.1	Flow Chart of Resonator on UWB Antenna Design Methodology	28
Fig. 4.2	Ultra Wideband	28
Fig. 4.3	Antenna with SIR and SRR Loaded along Feed Line	29
Fig. 4.4	Return Loss of Simple Circular Monopole Antenna	29
Fig. 4.5	Antenna with SIR on Left Side of the Feed Line	30
Fig. 4.6	Return Loss i.e. S11 Parameter of Antenna with SIR on Left Side of the Feed Line	31
Fig. 4.7	Antenna with SRR on Right Side of the Feed Line	31

Fig. 4.8	Return Loss i.e. S11 Parameter of Antenna with SRR on Right Side of the Feed Line	32
Fig. 4.9	Antenna with SIR and SRR on the Feed Line	32
Fig. 4.10	Return Loss i.e. S11 Parameter of Antenna with SIR and SRR on the Feed Line	33
Fig. 4.11	Voltage Standing Wave Ratio	33
Fig. 4.12	Configuration of Proposed Antenna	35
Fig. 4.13	Circular Monopole Antenna	35
Fig. 4.14	Simulated S11 Parameter of Circular Monopole Antenna	36
Fig. 4.15	Circular Monopole Antenna with SIR	36
Fig. 4.16	Simulated S11 Parameter of Circular Monopole Antenna with SIR	37
Fig. 4.17	Circular Monopole Antenna with SRR	37
Fig. 4.18	Simulated S11 Parameter of Circular Monopole Antenna with SRR	38
Fig. 4.19	Circular Monopole Antenna with SRR	38
Fig. 4.20	Simulated S11 Parameter of Circular Monopole Antenna with CSRR	39
Fig. 4.21	Circular Monopole Antenna with SIR,SRR and CSRR	39
Fig. 4.22	Simulated S11 Parameter of Circular Monopole Antenna with SIR, SRR and CSRR	40
Fig. 4.23	Voltage Standing Wave Ratio Curve	40
Fig. 5.1	UWB Antenna with Stub Loaded SIR	42
Fig. 5.2	Ultra Wide Band Antenna	43
Fig. 5.3	Return Loss Curve of UWB Antenna	43
Fig. 5.4	UWB Antenna with Stub Loaded SIR on the Left Side of Feed Line	44
Fig. 5.5	Return Loss Curve of UWB Antenna with Stub Loaded SIR on the Left Side of Feed Line	44
Fig. 5.6	UWB Antenna with Stub Loaded SIR on the Right Side of Feed Line	45

Fig. 5.7	Return Loss Curve of UWB Antenna with Stub Loaded SIR on the Right Side of Feed Line	45
Fig. 5.8	UWB Antenna with Stub Loaded SIRs Along Feed Line	46
Fig. 5.9	Return Loss Curve of UWB Antenna with Stub Loaded SIRs along Feed Line	46
Fig. 5.10	VSWR Curve when SIRs are Connected to UWB Antenna	47
Fig. 5.11	Current Distribution of Antenna with Stub Loaded SIRs at 2.4GHz	48
Fig. 5.12	Current Distribution of Antenna with Stub Loaded SIRs at 3.5GHz	48
Fig. 5.13	Current Distribution of Antenna with Stub Loaded SIRs at 5.8GHz	48
Fig. 5.14	Current Distribution of Antenna with Stub Loaded SIRs at 7.5GHz	49
Fig. 5.15	Top View of the Antenna with Stub Loaded SIRs	49
Fig. 5.16	Bottom View of the Antenna with Stub Loaded SIR	50
Fig. 5.17	VNA Model No.N5222A	50
Fig. 5.18	Simulated Result of Stub Loaded SIRs on UWB Antenna using CST Studio 2010	51
Fig. 5.19	Measured Result of Stub Loaded SIRs on UWB Antenna using VNA	51

## LIST OF TABLES

Table 4.1	Parameters and its Optimized Value	34
Table 4.2	Comparison of Return Loss Values at Various Frequencies with Conditions of SIR and SRR	34
Table 4.3	Different Parameter and its Optimized Value	41
Table 4.4	Comparison of Return Loss at Various Frequencies with Different Resonator	41
Table 5.1	Comparison of Return Loss Values at Various Frequencies with Conditions of SIRs	47
Table 5.2	Comparison between the Simulated and Measured Result at Various Frequencies	52

## LIST OF ABBREVIATIONS

ANN	artificial neural network
BPF	band pass filter
CPW	coplanar waveguide
CSRR	complementary split-ring resonators
DNB	double notch-bands
DNG	double negative
DPS	double positive
EBG	electromagnetic band gap
ECA	equivalent circuit analysis
ENG	epsilon negative
FCC	federal communication commission
GA	genetic algorithm
GA-ANN	genetic algorithm artificial neural network
ITU-R	international telecommunication union radio communication sector
LHM	left-handed metamaterial
MCSRR	modified complementary split ring resonator
MMR	multi mode resonator
MNG	mu negative
MSRR	multiple split ring resonator
PEC	perfect electric conductor

SIR	stepped impedance resonator
SNR	signal to noise ratio
SR	spiral resonator
SRR	split ring resonator
SSRR	square split ring resonator
TFSIR	tri-section folded stepped impedance resonators
TSSIR	tri-section stepped-impedance resonator
UWB	ultra-wideband
VNA	vector network analyzer
VSWR	voltage standing wave ratio
WiMax	worldwide interoperability for microwave access
WLAN	wireless local area network

# INTRODUCTION

---

### 1.1 Overview

For present and future applications an ultra-wideband (UWB) technology is most interesting technology. UWB technology is encouraged mainly in 2002 as the US Federal Communication Commission (FCC) granted to utilize the unlicensed frequency band for communication purpose. However, there are many other existing communication systems such as WLAN system, WIMAX system having narrow band frequency range are also included in UWB range and causes interference. Interference can be avoided with these types of wireless systems by using a filter with band stop characteristics combined with UWB antennas to achieve a band notch function at the interfering frequency bands.

### 1.2 Ultra-Wideband Technology

Ultra-Wideband (UWB) is a short duration pulse. According to UWB definition any wireless system that has a fractional bandwidth larger than 20% and a total bandwidth exceed 500MHz. A UWB system is made up of various satisfying aspects such as high data rate, high accurate ranging, fading robustness, and low cost transceiver implementation etc.

### 1.3 UWB Advantages

UWB offers several advantages which are as under [1]

- High data rate: UWB having frequency in GHz, as frequency is high so it can supports high data rate with hundreds of Mb/s and covers up to the range of 0-10 meters.
- Minimum penetration loss: It can operate in both line-of-sight and also in non-line-of-sight environments as it can enter obstacles with minimum loss.
- Fading robustness: UWB system has immunity to multipath. Due to its fading robustness the transceiver complexity can be reduced.
- Security: UWB signal is noise like because of its low energy density so it is difficult to detect by other users. In this way UWB is most secure system.
- Low cost: UWB system is less complex so it is of low cost.
- Less power consumption.

## 1.4 UWB Importance

The AWGN channel capacity as given by Shannon's theorem

$$C = B \log_2 (1 + \text{SNR}) \quad (1.1)$$

where C is the channel capacity in bits per second,

B is the channel bandwidth in Hz, and

SNR is the signal-to-noise ratio.

- The channel capacity can be increased by increasing the signal bandwidth at low signal to noise ratio therefore there will be high data rate.
- Low power needed in transmitter as output power is small which is in milliwatt.

## 1.5 Drawbacks of UWB

- Power limitation that restricts UWB operation to about 10m at around 100 Mbps.
- Other wireless standards such as WLAN, WiMax causes interference in UWB during transmission. UWB antenna suffers from interference because of different wireless standards. So some techniques are required to notch undesired frequencies.

## 1.6 Techniques Used for Notching in UWB Antenna

- Etching slots on UWB
- Electromagnetic band gap structures
- Stepped Impedance resonator
- Split ring resonator
- Complimentary split ring resonator
- Meander line resonator

In this thesis, different resonators are connected to UWB antenna for notching specific interfering bands.

## 1.7 Objective of Thesis

- To study various method used for band notching in UWB antenna.
- Design and simulate UWB antenna with filter for rejection of triple interfering bands using SIR and circular SRR.
- Design and simulate UWB antenna with filter for rejection of quadruple interfering bands using SIR, square SRR and CSRR.

- Design and simulate UWB antenna with filter for rejection of quadruple interfering bands using stub loaded SIRs along the feed line.
- Fabrication of the proposed structure and testing it and comparing them with simulated results.

## **1.8 Thesis Organization**

The thesis is divided into six chapters

Chapter 1, is giving overview of UWB technology. Advantages and disadvantages are also explained. Main flaw in UWB is interference caused by wireless standards and other system.

Chapter 2, includes the literature survey on the notching of bands in UWB. There are different techniques such as EBG structures, folded strips, etching slots, and resonators etc. are used for notching undesired frequency bands.

Chapter 3, different type of resonators with their mathematical analysis is discussed. Resonators such as SIR, SRR, CSRR and Stub loaded SIR are used for removal of undesired frequency.

Chapter 4, triple and quadruple band rejection by using split ring resonator, complementary split ring resonator and stepped impedance resonator is discussed.

Chapter 5, give rejection of quadruple interfering bands and improvement in VSWR using stub loaded SIRs are designed and simulate. Testing and fabrication of designed antenna are also done.

Chapter 6, conclusion and future work are discussed.

## LITERATURE SURVEY

---

In this chapter, different kinds of techniques are discussed for the rejection of interfering bands. These techniques involve EBG structures, folded strips, etching slots, and resonators etc. for notching purpose. The main attention is paid on total number of bands rejection, size reduction of the antenna and the bandwidth enhancement.

### 2.1 Research Paper Literature Survey

**Yan Zhang, Wei Hong, Zhen-Qi Kuai and Jian-Yi Zhou[2]** designed a stepped impedance resonator and a split ring resonator integrated on feed line of a compact circular monopole ultrawide band (UWB) antenna. This stepped impedance resonator and split ring resonator forms a filter for notching multiple interfering narrow bands. SIR notches the frequencies 2.4GHz and 5.8GHz and SRR notches 3.5GHz. The size of whole antenna is very compact and of low cost. The advantage of circular monopole antenna in UWB applications is its ultrawide impedance bandwidth and easy fabrication. The band rejected filter is made by two dissimilar types of resonators coupled to the feed line of antenna. For matching impedance, a tapered line is used between the antenna and the band stop filter.

**Liang Chen, Xiaoyan Zhang, Bian Wu[3]** represented a dual notched bands with deep and sharp skirts at frequency 5.8GHz, 8GHz by using cascaded T-shaped stub loaded stepped impedance resonators on a compact ultra-wideband (UWB) filter. There is coupling between shorted-stub loaded SIR and multimode resonator (MMR). The UWB filter includes multi mode resonators with stub on it and a feed line. The proposed antenna notch undesired WLAN and satellite communication signals. Frequency range of UWB filter is 2.9GHz to 10.6GHz having .5dB insertion loss in passband.3dB fractional bandwidths are 2.6% at 5.8GHz and 3.7% at 8GHz and 30dB attenuation at centre of notch.

**Jianxin Liang, Choo C. Chiau, Xiaodong Chen and Clive G. Parini[4]** designed a novel ultrawide-band (UWB) circular monopole antenna. It has been investigated that how a parameter can affect the performance of antenna. A circular monopole antenna with satisfactory radiation pattern has been demonstrated. A 50  $\Omega$  microstrip line,

substrate, planar circular disc are used to design a UWB antenna with 10 dB return loss bandwidth. Whole antenna's performance depends on feed gap, radius of circular patch and width of ground. The dimension of circular disc decides the first resonant frequency as the distribution of current is along the edge of circular disc. It is verified that the printed circular disc monopole covers an ultra wide bandwidth which is defined by FCC. It is realized that the radiation patterns are omnidirectional.

**Isha Jindal and Rajesh Khanna[5]** used a UWB antenna having range 2.2GHz to 10GHz. Some interfering bands included in this range. Two SIR are introduced to notch multiple narrow bands. Notched frequencies are 2.4GHz, 3.5GHz, 5.8GHz and 8.7GHz. Wave cancellation principle is discussed which tells about how notching takes place in UWB. Each resonator notches two frequencies. At resonating frequencies current does not reach at antenna and there will be rejection of undesired frequencies. In this article, different electrical lengths of transmission line are used and are connected to form stepped impedance resonators (SIRs) coupled to the both sides of the feed line provide different paths. The fundamental and spurious frequencies are frequencies at which resonance condition take place that means notching is obtain at these frequencies.

**D.O. Kim, N.I Jo, H.A. Jang and C.Y. Kim[6]** introduced a quadruple notch bands by using co-directional complementary split ring resonators(CSRRs) in ultra wide band (UWB). The final structure achieves impedance matching plus resonances at four notch band. A compact structure is formed and mutual coupling between resonators and UWB antenna is minimized. This novel antenna has the advantage of suitable implementation and affordable, because the etching of the CSRR along feed line are on a single-layer and single sided of substrate which makes it less costly and easier fabrication. This antenna is loaded with a CSRRs bandstop filter to notch the undesired signal.

**Debdeep Sarkar, Saptarshi Ghosh, Somak Bhattacharyya and Kumar Vaibhav Sriavstava[7]** presented a ultra wideband planar monopole antenna which is integrated by CSRR and mushroom EBG elements to notch dual band. A UWB monopole antenna covers the range from 3.1-10.6GHz. Dual bands rejection are IEEE802.11a and X band with good average gain and at these frequencies VSWR >2. A strong notch band is achieved by modified mushroom cell having bandwidth 5.15-5.85 GHz. Additionally notch frequency range 7.9-8.4 GHz can be obtained by etching a CSRR on the junction of

feed line and circular patch so that X band communication is also rejected. This novel antenna also gives far-field radiation pattern in the radiating band.

**Morikazu Sagawa, Mitsuo Makimoto and Sadahiko Yamashita[8]** designed stepped impedance resonators of  $\lambda_g/4$ ,  $\lambda_g/2$  and  $\lambda_g$ . In this paper, these three types of SIRs are investigated and saw their fundamental characteristics and their applications.  $\lambda_g$  type SIR's formula is derived. Relation between spurious frequency and fundamental frequency is also discussed. Transmission-line resonators with a simple structure have usually been used in filters and oscillators for easy analysis and accurate design forecast. However, not only fundamental performances such as compactness and high value, but also functional characteristics such as spurious suppression and affinity to active devices, have been strongly required. That is, compact resonators with high value and high quality performances are earnestly desired.

**Yuan Yao, Bin Huang and Zhenghe Feng[9]** designed a circular ultra wide band having range from 3.1GHz to 10.6GHz. This antenna is composed of a semicircular arc cut on the circular patch to obtain a notch frequency. The dimension of the slot is calculated in this paper and has length of one half wavelength of particular rejected frequency. It is a simple circuit as it does not require any filter to reject particular frequency. In this paper a wide slot antenna fed by ultra-wideband microstrip-line having frequency band-notch function is presented. This UWB antenna is collection of a circular microstrip patch and a semicircular arc cut on the ground of the microstrip line. A simple arc-shaped slot in the circular microstrip patch is required for notching bands. With the proposed antenna design, band-notched can be easily obtained without the use of external filters, which can greatly simplify the circuit design of a communication system.

**Filiberto Bilotti, Alessandro Toscano and Lucio Vegni[10]** presented a metamaterial which have both MNG materials and artificial magneto dielectrics. The extension of SRR is known as multiple split ring resonator which is described in this paper. In this paper a spiral resonators (SRs) is also discussed. Reduction of electrical dimension can be done by using conventional printed circuit technologies. Further electrical dimension reduction is possible by using MSRR and SR of high permittivity substrate and lithographic processes. A mathematical analysis of the equivalent circuit models for both the inclusions has been developed, and a proper comparison with other models has been presented. The former inclusion has been shown to achieve miniaturized linear

dimensions of the order of  $\lambda_0/30$ - $\lambda_0/40$  , while, by using the latter inclusion, it is possible to achieve even smaller electrical dimensions of the order of  $\lambda_0/65$ - $\lambda_0/250$ , making use of conventional printed circuit technologies. After this more reductions of the electrical dimensions of the resonators can be achieved by backing the inclusions with a high-permittivity substrate and by using more expensive high-precision lithographic processes. Lastly, some comments about the quality factor of MSRRs/SRs and their possible applications is given.

**M. Nosrati and M. Daneshmand[11]** highlighted wave's cancellation theory to realize multiple notch bands in UWB. Firstly, it designed a new configuration of UWB pass band filter having micro-strip transmission line for notching unwanted frequencies. Notching can be done by using two parallel SIRs with different electrical length and different impedance to provide different path. In whole process a wave cancellation theory is introduced to reject undesired signals. The tri-section SIR (TSSIR) is used for notching purpose. Its fundamental and first spurious resonance frequencies are chosen in such a way that resonance condition is satisfied at these frequencies. The main advantage of using the proposed concept to avoid via holes, as in conventional notch filter plus 75% of size reduction in comparison with the conventional band pass filter.

**D. R. Smith, Willie J. Padilla, D. C. Vier, S. C. Nemat Nasser and S. Schultz[12]** defined “left-handed ” structure and predicted Snell's law, Doppler effect. All these phenomena are inverted when metamaterial is used. Such material has negative value of permeability and permittivity. Negative permeability is because of gaps in split ring resonator and negative permittivity is because of conducting metal. By having gaps in the rings of SRR there is no requirement of half wavelength for resonance that means wavelength at resonance is greater than diameter of ring. But in closed ring there is requirement of half wavelength at resonance. The reason of the small split ring inside a big ring, whose split is leaning opposite to the big ring, is to create a high capacitance in the small gap section between the rings.

**M.R. Vidyalakshmi and Dr.S.Raghavan[13]** introduced three algorithm applied to the square split ring resonator. These three algorithms are genetic algorithm (GA), hybrid genetic algorithm artificial neural networks (GA-ANN) and artificial neural networks (ANN). These algorithms are adopted to reduce the size of split ring resonator or to reduce error in resonant frequency. Dimension of SSRR are optimized which are length,

width of conductor and gap between conductor with respect to wanted resonant frequency.

**N.I Jo, C.Y. Kim, D.O. Kim and H.A. Jang [14]** described a quadruple band rejection properties in UWB antenna. Basically, small antennas acquire many disadvantages such as spatial limitations and coupling problems. To rise above the spatial limitation of the compact antenna, the split ring resonator SRR and CSRR are used, whose purpose is to reject bands which are inserted into the antenna. Concerning gaps between two-ring of the SRR and CSRR in a best way to remove coupling limitations of the UWB antenna, while this antenna covers the frequency band from 3.1 to 10.6GHz but abolish the multiple bands.

**D. Bhardwaj, D. Bhatnagar, S. Sancheti and B. Soni [15]** highlighted the deviation of resonant frequency with the deviation in the notch angle. If the notch angle is between  $164^\circ$  to  $180^\circ$ , single resonance frequency is achieved while if the notch angle is less than  $164^\circ$ , two resonant frequencies are achieved with enhanced bandwidth characteristics. Notching at three frequency bands can be achieved by using triangular notch on which its notch i.e. the depth of the notch tip on the square patch antenna concludes its performance. The two resonant frequencies are such that one is below the resonant frequency of the square patch without notch and other is above it. As the notch angle decreases the path length of patch current raises which progresses the performance of the antenna. It is basically used for WiMAX applications.

**Su Sander Thwin[16]** discussed a semi circular slot which is implanted on the radiating path which is a planar inverted cone. Beside this antenna had partially tapered ground plane for impedance matching. The notch frequency can be adjusted by varying total length and width of the semicircular slot. It provides just single band notched antenna where rejection is at 5-6GHz WLAN band. The semi-circular slots offer resonance frequency and the cancellation of current results in notching. To mitigate the potential interference between the UWB system and narrow band system such as WiMAX and WLAN, the semi-circular U and inverted U shaped slot resonators were added for band rejection purpose.

**Ming-Chun Tang, Shaoqiu Xiao, Tianwei Deng, Duo Wang, Jian Guan, Bingzhong Wang and Guang-Ding Ge[17]** presented a compact triple stop band UWB antenna is used to avoid interference difficulty. As we know due to presence of nearby

communication systems generates interference in the UWB operating frequency. This antenna, used for the notching of interference with Worldwide Interoperability for Microwave Access (WiMAX) covering 3.3-3.6GHz frequency and lower and upper wireless local area networks (WLANs) 5.15–5.35 GHz and 5.725–5.825 GHz, provides triple notched bands by only one structure with simple design. The proposed antenna had wide bandwidth from 3.03 to 11.4 GHz with triple undesired band-notches. Discussed different types of SRR such as single SRR, edge-coupled SRR, co-directional SRR.

**Chun Yan Song, Ting Yi Yang, Wei Wei Lin and Xiao Lin Yang[18]** discussed a new band-notched ultra wideband (UWB) antenna having electromagnetic band-gap (EBG) structure on feed line of antenna. EBG structures are used in a UWB antenna to generate a stop band. Several main parameters of the novel antenna are also talked about. The EBG structure has high impedance surfaces in a particular frequency band. It will not enhance the dimensions of the antenna by concerning EBG structure in the band-notched antenna design. Radiation patterns, mainly in the H-plane, are identical and nearly omnidirectional at 2 - 12 GHz. The operation frequency is from 10 GHz to 12 GHz, as the reflection phase of the EBG is from  $-90^0$  to  $90^0$ . The dominant mode in the microstrip line is quasi-TEM and the cut-off frequency is zero. Then, without EBG structure, there would be no band notch. But, a stop band turns up at about 7 GHz. In brief it indicates that the EBG structure accounts for the stop band.

**Parisa Lotfi, Mohammadnaghi Azarmanesh and Saber Soltani[19]** presented a asymmetric coplanar strip (ACS)-fed monopole antenna having size  $14 \times 16 \text{ mm}^2$  that has a opposite reconfigurable performance with ability to activate in the frequency range from 3.2 to 11 GHz with dual notch bands of 3.3–4.2 and 5–6 GHz and three notch frequency bands of 2.4–2.9, 3.6–4.4, and 5–6 GHz is obtained. The UWB antenna uses a patch of rectangle shape with rejecting elements such as folded shape slit and stub and the antenna uses resonating elements such as an arc-shaped stub and reversed L-shaped stub. The better performance is attained by a rotation of circular patch. A stepper motor is used to organize the rotation of the patch and start the resonating elements. There are two cases by rotating the circular substrate and patch namely the dual band-notched UWB frequency case and the triple-mobile-band case. This antenna can be used the complementary mobile or UWB applications because of its compact configuration and compact size, good radiation patterns and gain, and easy fabrication with low cost.

**S. Raghavan, A. Subbarao and M. Ramaraj[20]** highlighted a compact microstrip-fed antenna is used for Ultra-wide band applications. The antenna has size of  $25 \times 30 \text{mm}^2$ . The antenna has -10dB impedance bandwidth from 2.7 GHz to 12 GHz. The antenna has constant gain and stable radiation pattern. Later, the design was modified with complementary split ring resonator (CSRR) slot to remove interference from 5-6 GHz WLAN band. For UWB applications a hexagonal monopole antenna with a half circular slot in ground plane is discussed. The antenna has operating bandwidth from 2.7 GHz to 12 GHz, which fully covers bandwidth specified by FCC.

**Debdeep Sarkar, Kushmanda Saurav and Kumar Vaibhav Srivastava[21]** described a CSRR-loaded microstrip patch antenna located on a defected ground structure. The novel compact dual-band antenna simultaneously suits WLAN and WiMAX application, providing a appreciably wide impedance bandwidth ( $S_{11} < -10 \text{ dB}$ ) in the WLAN and upper WiMAX frequency regions. In the two frequency bands of operations the gain and efficiency of the antenna are also very adequate. To achieve dual bands meta-resonators (CSRRs) and partially defected ground structure is used. The dual-band can be obtained by CSRRs, whereas bandwidth enhancement in the WLAN and upper WiMAX band can be obtained by partially defected ground structure. The application of proposed antenna is that it is used in wireless communication systems where integrated antenna covering both WLAN and WiMAX bands which is the main objective.

**D. O. Kim and C. Y. Kim[22]** proposed a compact ultra-wideband (UWB) antenna with dual band-notched design. The antenna consists of a rectangular metal patch and a 50 ohm coplanar waveguide (CPW) transmission line. By etching both the first iteration and the third iteration Hilbert-curve slots on the radiating patch, band-rejected filtering properties in the WiMAX/WLAN bands can be obtained. Furthermore, each notched band can be easily tuned by adjusting the length of each Hilbert-curve line segment because the sum of whole line segment controls the corresponding resonance frequency. The proposed antenna is simulated, designed, and measured showing a broadband matching and a stable radiation performance over the entire UWB frequency range, which prospects the deployment in the UWB system. As will be seen, the operation bandwidth of the antenna is from 2.5 to 10.6 GHz for  $V_{\text{SWR}} < 2$ , in which two frequency rejection bands from 3.3 to 3.7 GHz and from 5.4 to 6 GHz for  $V_{\text{SWR}} > 2$  can be achieved.

**Chaabane Abdelhalim and Djahli Farid [23]** discussed a compact planar ultra wideband (UWB) monopole antenna with triple rejection band. The proposed antenna consists of a stair cased V-shaped conducting element and partial ground plane. The triple rejection band is accomplished by implanting two different vertical up with a vertical down C-shaped slots in the conducting patch and in the ground plane, respectively. Moreover, the bandwidth of each notched band can be independently controlled by regulating the dimensions of the band notched structure. The antenna operates until upper 11 GHz for voltage standing wave ratio (VSWR) less than 2, and shows bands rejection of 1.6-2.66 GHz (49.76%), 3-4 GHz (28.57%), and 5.13-6.03 GHz (16.12%). It minimizes the interferences in the UWB communication systems with the wireless systems, in low cost with controllable triple band notched characteristics. Two different vertical up with a vertical down C-shaped slots are connected in the conducting patch and in the ground plane, for rejecting wireless systems frequency bands. The notched band frequency can be controlled by regulating length and width of the band notched structure.

**V. G. Veselago[24]** showed the property of wave propagation when substances with negative value of permittivity and permeability. If the value of  $\epsilon, \mu$  is greater than 0 then electric field, magnetic field and wave vector forms right hand and if  $\epsilon, \mu$  is less than 0 forms left handed material. In right handed pointing vector  $S$  and  $k$  is in the same direction and in left handed  $S$  and  $k$  is in opposite direction. Satisfy negative group velocity and vector  $k$  is in same direction of phase velocity. Show phase velocity is opposite to the energy flux and follows reversed Doppler Effect.

**Chao-Huang Wu, Shih-Fong Chao, Zou-Ming Tsai, Huie Wang and Chun Hsiung Chen[25]** developed a switchable bandpass filters by loading diodes at one end of stepped impedance resonators. The loaded diodes are used to change the resonance properties of stepped impedance resonators. Here the resonance properties of the stepped impedance resonators are mathematically derived with different loads at one end. When the filter is switched on bandpass response change to wide notch band by having same fundamental resonant frequency of the on state coupled resonators but different spurious frequencies. A high and wideband isolation is achieved in the off state resonators by misaligning the resonant modes when the switch is off. In the design two or three switched stepped impedance resonators are used by switchable microstrip bandpass filter.

**Mehdi Nosrati and Miladi Mirzaee[26]** used a new technique to reduce size and enhancement in the bandwidth of bandpass filter by using multimode resonator. A spiral transmission line is loaded in the filter to enhance the bandwidth and further reduction is also analyzed for this type of bandpass filters. A UWB antenna is having wide bandwidth uses this technique to increase bandwidth and improve the tuning of the transmission zeros. The bandwidth is increased up to 12.6% and size is reduced up to 70% by using this technique. The proposed band pass filter provides a relatively wide 3dB fractional bandwidth of 72.6% frequency response with two transmission zeros at the lower and upper stop bands to provide a very sharp cutoff, low pass band insertion loss and good return loss characteristics.

## **2.2 Conclusion**

In this chapter, we have discussed different methods to reject interfering bands in UWB antenna. Stepped impedance resonator, split ring resonator and complimentary split ring resonator are resonators used to reject more number of interfering bands in comparison to other resonators. To improve the VSWR stub loaded SIR can be used. Stub loaded SIRs are easy to implement and can filter the multiple interfering bands. In the next chapter different types of resonators are described for notching undesired frequency bands in UWB.

## DIFFERENT TYPES OF RESONATORS FOR NOTCHING

A device which shows resonant behavior i.e. at some frequencies oscillation takes place having greater amplitude than other frequencies. This frequency is known as resonant frequency and this device is known as resonator. A resonator can be used to create a signal of a definite frequency or it can notch a particular frequency. In this chapter we will discuss different types of resonators to notch interfering bands such as WLAN, WiMAX etc. in UWB. Stepped impedance resonator, split ring resonator, complementary split ring resonator and stub loaded stepped impedance resonator are examined here. These resonators are applied to filter resonant frequencies. Distributed circuits are used to notch high frequencies whereas lumped circuits cannot be used at high frequencies, lumped circuits are only useful in low frequency applications. That is why, distributed circuits are used to design these resonators.

### 3.1 Stepped Impedance Resonator

As its name suggests the transmission line is in the form of steps. That means there is a discontinuity in a transmission line. When two or more transmission lines are attached having different electrical lengths and different impedances then there will be the formation of SIR. There are different types of structures of SIR as shown in Fig. 3.1

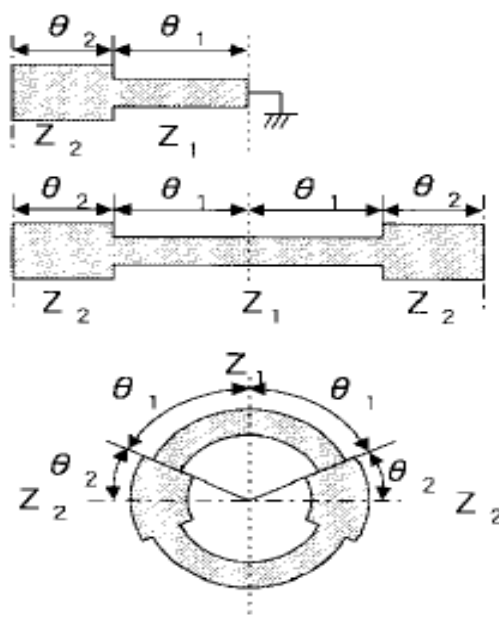


Fig. 3.1. Basic Structure of SIR (i)  $\lambda_g/4$  type, (ii)  $\lambda_g/2$  type and (iii)  $\lambda_g$  type [8]

### 3.1.1 Wave Cancellation Theory

A wave cancellation theory is used for notching single or multiple bands in the UWB bands. A stepped impedance resonator is coupled to the feed line of UWB antenna having different electrical length and different impedance. The fundamental frequency and spurious frequencies are the frequencies at which stepped impedance resonator satisfies resonance conditions. The number of bands to be rejected can be obtained by selecting the fundamental frequency and spurious frequencies of Stepped Impedance Resonator (SIR). If only single notch band is required then there is no use of spurious frequencies of the Stepped Impedance Resonator (SIR). Current will not reach to the antenna at fundamental frequency, as resonators will satisfies resonance condition in this way a stop band is obtained. If stepped impedance resonators (SIRs) will resonate at those spurious frequencies then multiple notch bands is obtained. In this way multiple rejection bands are obtained [11].

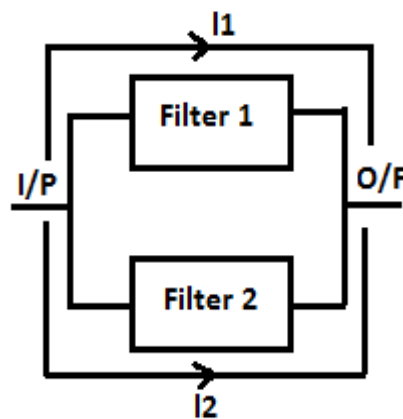


Fig. 3.2. Filters are Connected in Parallel [11]

To notch multiple frequency bands by Stepped Impedance Resonator (SIR) the wave's cancellation theory is suggested. In Fig. 3.2, we have considered two band pass filter having same input signal. Now this input signal generates two different paths and hence resulting in different frequencies to be passed at different times. The output provided by two filters are added either constructively or destructively at the output terminal. It provides either removal or pass of band depending upon the construction or destruction at the output terminal. According to waves cancellation theory, when two signals from both filters have  $180^\circ$  phase shift and equal amplitude, they cancel out each other i.e. they are added destructively and hence a notch band is introduced at that particular frequency. The two paths provided by filters should have a phase difference of  $180^\circ$  and they should satisfy the condition-

$$|\beta_1 l_1 - \beta_2 l_2| \cong (2n + 1)\pi \quad (3.1)$$

where,  $n=0,1,2,\dots$

$\beta_1, \beta_2$  are the phase constants

$l_1, l_2$  are the physical lengths of filters respectively.

A UWB antenna is a type of filter which passes wide frequency and other filter is formed by SIR. According to wave cancellation theory, when input is applied to the port reaches to both the filter. At the output terminal, both signals are added having phase shift of  $180^\circ$  and equal amplitude at particular frequency, they cancel out each other. In this way notching of interfering bands can be done by using wave cancellation theory.

### 3.1.2 Basic Structure and Mathematical Analysis of SIR

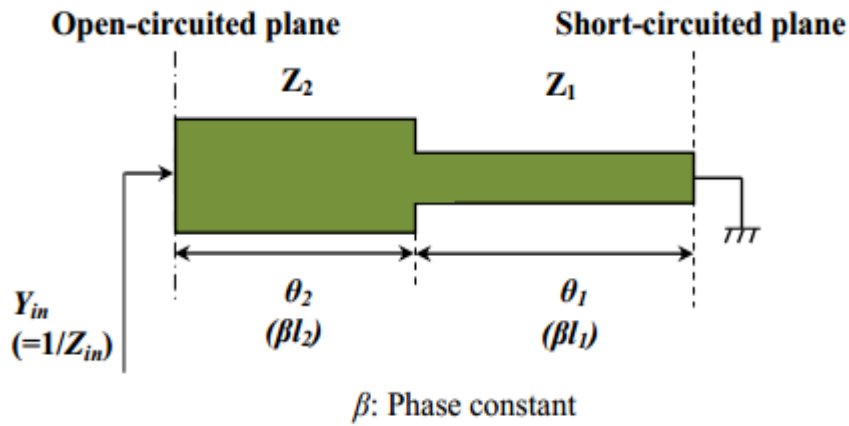


Fig. 3.3. Basic Stepped Impedance Resonator [34]

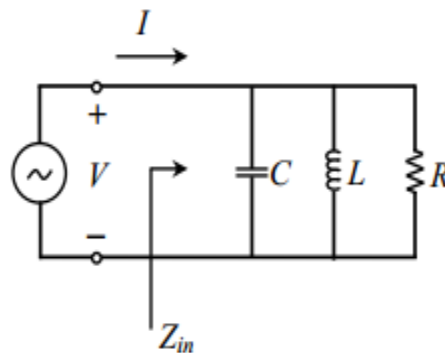


Fig. 3.4. Equivalent Circuit of Stepped Impedance Resonator [34]

The simple stepped impedance resonator (SIR) is shown in Fig. 3.3 and its equivalent circuit is shown in Fig. 3.4. In this case, we have two transmission lines with different impedances having different lengths. Its one side is open and other side is short [8]. The admittance of SIR from the open plane is as follows:

$$Y_i = jY_2 \frac{Y_2 \tan \theta_1 \tan \theta_2 - Y_1}{Y_2 \tan \theta_1 + Y_1 \tan \theta_2} \quad (3.2)$$

where,  $Y_1$  and  $Y_2$  are admittance of two different transmission line of SIR.

After satisfying resonance condition  $Y_i = 0$ , there will be some relation between electrical length and impedance ratio as in (3.3)

$$\tan \theta_1 \tan \theta_2 = R_z \quad (3.3)$$

where,  $R_z$  is impedance ratio and  $\theta_1, \theta_2$  are electrical length of two different lines in SIR.

$$\theta_r = \theta_1 + \theta_2 \quad (3.4)$$

If  $\theta_1 = \theta_2 = \theta$ , we have

$$\theta = \tan^{-1} \sqrt{R_z} \quad (3.5)$$

$\Theta$  is the electrical length and mathematically, it is denoted as:

$$\beta l = \Theta \quad (3.6)$$

$f_0$  is fundamental frequency and if  $f_1, f_2, f_3$  are spurious frequencies. Spurious frequency can be calculated by:-

$$\frac{f_1}{f_0} = \frac{\pi}{\tan^{-1}(\sqrt{R_z})} - 1 \quad (3.7)$$

$$\frac{f_2}{f_0} = \frac{\pi}{\tan^{-1}(\sqrt{R_z})} + 1 \quad (3.8)$$

$$\frac{f_3}{f_0} = \frac{2\pi}{\tan^{-1}(\sqrt{R_z})} - 1 \quad (3.9)$$

where,  $R_z = Z_2/Z_1$

If we know the value of impedances of each section then the width of the same section can be determined by using the characteristic impedance of the microstrip line:

$$Z_0 = \frac{60}{\sqrt{\epsilon_e}} \ln \left( \frac{8d}{W} + \frac{W}{4d} \right) \quad \text{for } \frac{W}{d} \leq 1 \quad (3.10)$$

$$Z_0 = \frac{120\pi}{\sqrt{\epsilon_e} \left[ \frac{W}{d} + 1.393 + 0.667 \ln \left( \frac{W}{d} + 1.444 \right) \right]} \quad \text{for } \frac{W}{d} \geq 1 \quad (3.11)$$

where,  $W$  is width of microstrip line,  $d$  is the height of microstrip line and  $\epsilon_e$  is effective dielectric constant.

### 3.2 Metamaterial

Metamaterial refer to material having properties which are not found in nature. It is beyond conventional materials. The conventional materials have lattice constants much smaller than the wavelength of incident radiation. The electric field component of a signal

when incident on such materials agitates the electric dipole which reradiates with certain retardation. Thus we achieve the electric permittivity value,  $\epsilon$  other than one. Refractive index is originated by the excitation and reradiation with certain retardation. The Refractive index shows how the signal is slowed down in a particular medium compared to its speed in the vacuum. In this type of dielectrics, mainly at higher frequencies magnetic permeability is unity  $\mu=1$  because there is no excitation of magnetic dipoles. The lattice constant is also smaller than the wavelength of incident radiation in metamaterial. Now, we want to obtain a permeability  $\mu \neq 1$  unlike conventional materials employing artificial building blocks (atoms). Even negative values of magnetic permeability can be obtained. Generating of a negative electric permittivity is not a big deal as it can be found in some naturally occurring materials like metals. Thus, this type of material named as metamaterials having negative refractive index,  $n = -\sqrt{\epsilon\mu}$  [24]. Such type of metamaterials are called left-handed or Veselago materials named after Victor Veselago who first purposed this idea in 1968. Different classification with different wave vectors is shown in Fig. 3.5.

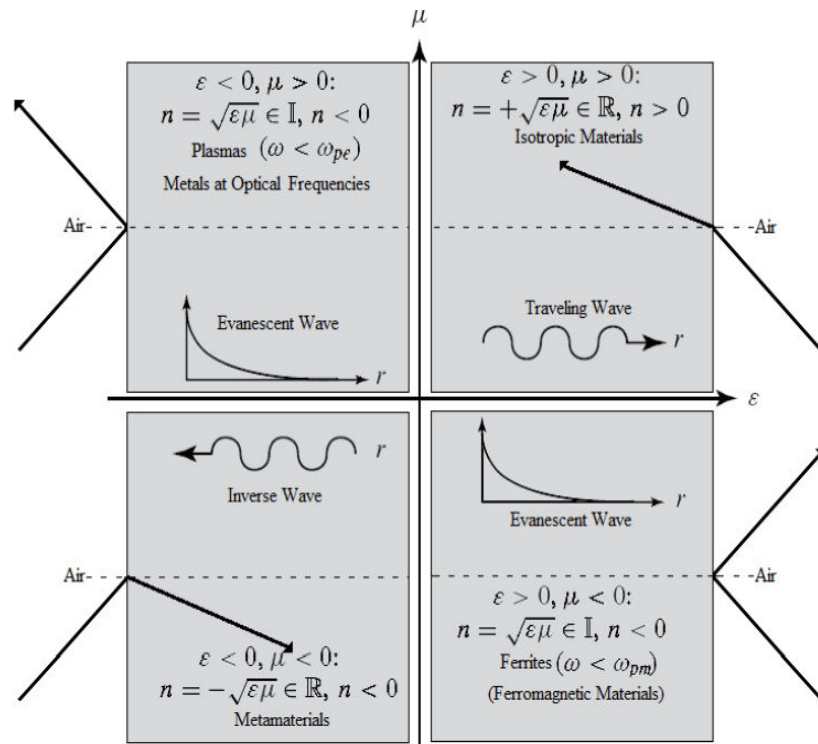


Fig.3.5. Classification of Materials (DPS : double positive, ENG: epsilon negative, DNG: double negative, MNG: mu negative)[33]

In the conventional materials a forward propagating wave is obtained having both  $\mu$  and  $\epsilon$  positive while in those type of materials where either  $\epsilon$  or  $\mu$  are negative we get a

decaying wave. Whereas in metamaterial a backward propagating wave is obtained having both  $\mu$  and  $\epsilon$  negative. These types of materials have anti parallel phase and group velocities. Thus the direction of propagation is opposite to the direction of flow of energy [24]. This idea was given by Vaselago in 1968 but much attention was not given at that time until 1999 when Pendry realized this idea [27]. As we can have negative refractive index in left handed materials, this means that the signal will bend towards the wrong side of the normal as shown in Fig. 3.6. This doesn't mean that these materials do not obey Snell's law. Snell's law is still valid in these types of materials provided the refractive index is negative.

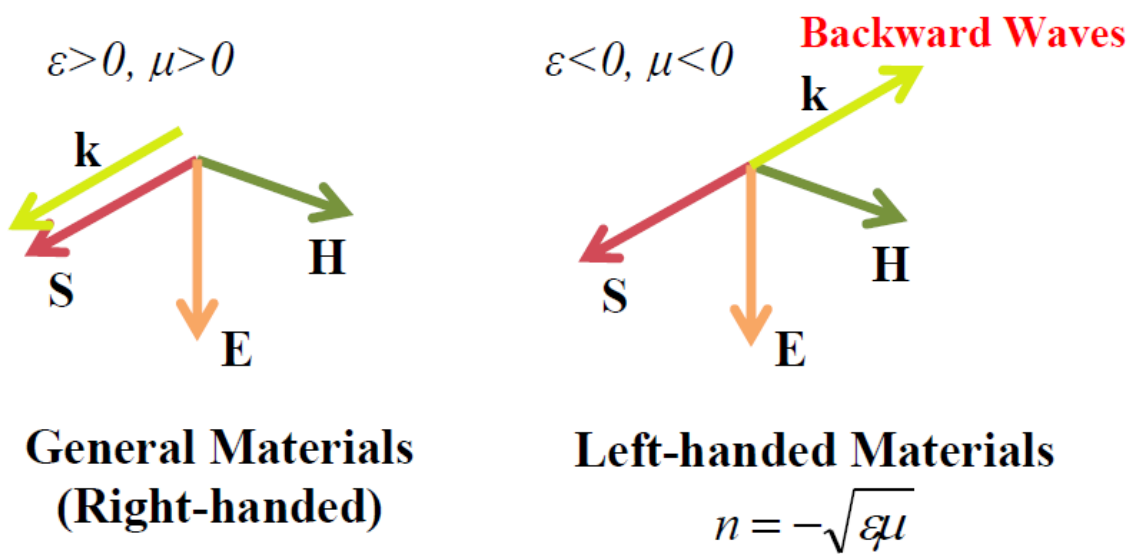


Fig. 3.6 The Diagrams of Electric Field, Magnetic Field, Wave Vector ( $E, H, k$ ) and Poynting Vector ( $S$ ) for Electromagnetic Wave Propagation in Right-handed and Left-handed Medium [24, 32]

### 3.2.1 Split Ring Resonator

Split ring resonator is a type of metamaterials which is artificially fabricated design. SRR is made of metals like silver, gold, aluminum or copper so that there is negative permittivity with a split introduced in their structure as shown in Fig. 3.7. They are left handed materials and for certain geometries they help us to achieve magnetic response and negative  $\mu$  at higher frequencies. [27]

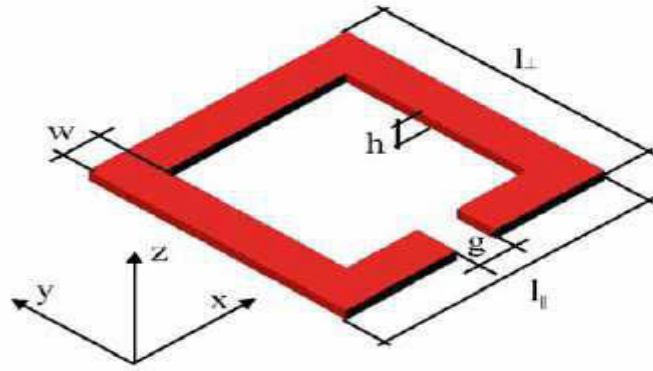


Fig. 3.7. Split Ring Resonator [28]

### 3.2.1.1 Physics of SRR

As mentioned before, SRR are metallic rings which is made of metal with certain gaps are established in some divisions of its structure. When a current circulates a magnetic coil we get a magnetic dipole moment. The generated dipole moment vector is perpendicular to the plane of the magnetic coil. The grouping of a magnetic coil with a plate capacitor forms an LC equivalent circuit and thus there will be an increased dipole moment at its resonant frequency [29]. The metallic ring acts as a coil (inductance L) and the split in the ring creates a parallel plate capacitor (capacitance C).

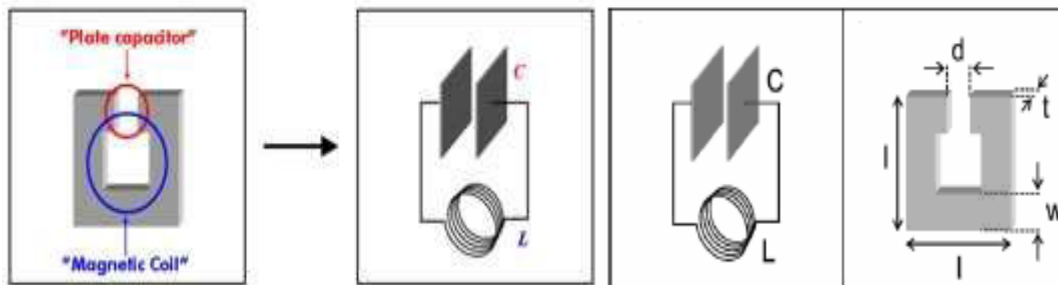


Fig 3.8. Analogy of SRR with LC Circuit [30]

Fig. 3.8 shows a SRR and its equivalent circuit. We can calculate different parameters by using basic formulae of capacitance and inductance.

The resonant frequency of SRR can be derived by the help of different parameter and these parameter are defined as follows [29]

$$\text{As Capacitance, } C = \epsilon_0 \epsilon_r (A/d) = \epsilon_0 \epsilon_r (wt/d) \quad (3.12)$$

where, A is area of SRR and d is gap between ring.  $\epsilon_r$  is relative dielectric constant.

$$\text{Inductance } L = \mu_0 (l^2/t) \text{ with a single turn in the coil} \quad (3.13)$$

And the LC resonance frequency is given as

$$\omega_{LC} = \frac{1}{\sqrt{LC}} \quad (3.14)$$

If we initiate the split in SRR by  $d=0$ , then the capacitance value will be infinity and resonance condition will not be satisfied. Thus it is necessary to initiate the split in the ring to have a capacitive effect. There are two conditions out of which if even one is satisfied, we get the coupling of the incident signal with the LC resonance [30]. First there is a component of electric field of signal perpendicular to plates of the capacitor (faces of the split) and the second is that the magnetic field vector is perpendicular to the plane of SRR. When the second condition is fulfilled we get the current in the coil which causes a magnetic field that counteracts the external magnetic field (Lenz law). This leads to the negative value of magnetic permeability,  $\mu$ .

### 3.2.1.2 Structure of Split Ring Resonator

The structure of the square split double ring resonator is as shown:

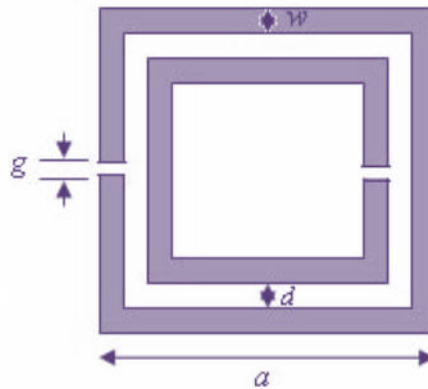


Fig. 3.9 Square Split Ring Resonator [13]

It consists of two square shaped rings with gaps in between them on the opposite side of both the rings. This structure is on a substrate. Here, 'a' denotes the length of the side of the square, 'w' denotes the width of the conductor 'd' denotes the dielectric width between the inner and the outer square and 'g' denotes the gap present in the rings. Care is taken that the gap width 'g' does not change from the inner ring to the outer ring.

### 3.2.1.3 Equivalent Circuit and Mathematical Analysis of SRR

One method of obtaining the resonant frequency is by using the equivalent circuit analysis (ECA) method. The given distributed network is converted into lumped network and analyzed. When a magnetic field is applied perpendicular to the plane of the ring, the

ring begins to conduct and gives rise to current flow. The current flowing through the rings will enable it to act as an inductor and the dielectric gap ( $d$ ) between the rings will lead to mutual capacitance. Hence the equivalent circuit of the SSRR will be a parallel LC tank circuit as shown in Fig. 3.10.

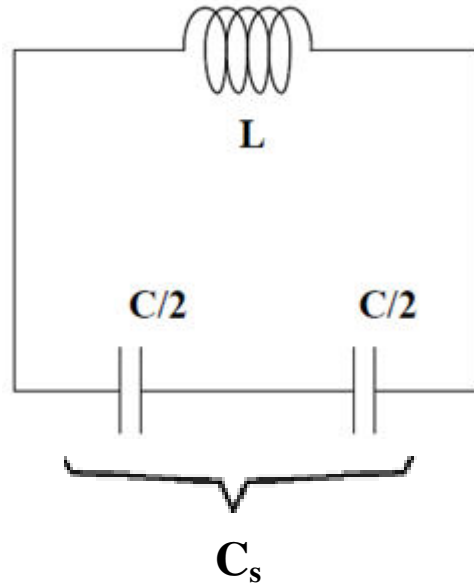


Fig. 3.10. Lumped Equivalent Circuit of SRR[31]

From this, we can calculate the resonant frequency

$$f_{LC} = \frac{1}{2\pi(\sqrt{LC_s})} \quad (3.15)$$

where,  $C_s$  is the equivalent capacitance and  $L$  is the effective inductance due to both of the rings.

The expressions for effective inductance and capacitances can be obtained as follows:

$$L = \frac{4.86 \mu_0}{2} (a - w - d) \left[ \ln\left(\frac{0.98}{\rho}\right) + 1.84\rho \right] \quad (3.16)$$

where,  $a$ ,  $w$ ,  $d$  are the notations prescribed in the previous section,  $\rho$  is the filling factor of the inductance and is given by :

$$\rho = \frac{w+d}{a-w-d} \quad (3.17)$$

The effective capacitance is given by

$$C_s = \left[ a - \frac{3}{2}(w+d) \right] C_{pul} \quad (3.18)$$

where,  $C_{pul}$  is the per-unit-length capacitance between the rings which is given as below

$$C_{pul} = \epsilon_0 \frac{K(\sqrt{1-k^2})}{K(k)} \quad (3.19)$$

$K(k)$  denotes the complete elliptical integral of the first kind with  $k$  expressed as

$$k = \frac{d}{d+2w} \quad (3.20)$$

Using the above expressions, the lumped equivalent of the SSRR is modeled. We are also able to infer that the circuit elements and hence the resonant frequency, depend on the dimensions of the resonator.

### 3.2.2 Complimentary Split Ring Resonator

Another resonator named complementary split ring resonator (CSRR) as shown in Fig. 3.11. The properties of the CSRRs show duals of those of the SRRs. The SRR behaves as a magnetic dipole and the CSRR works as an electric dipole. The equivalent circuit model shown in Fig. 3.12 has approximately the same configuration with the SRR's model. CSRR is excited by the E-field, the axis of the CSRR should be parallel to the E-field. The CSRR resonant frequency can be obtained by

$$\omega_{LC} = \frac{1}{2\pi(\sqrt{L_c C})} \quad (3.21)$$

Where,  $L_c$  is equivalent inductance and  $C$  is effective capacitance and inductance per unit length, respectively. By tuning the CSRR geometry, the capacitance and inductance values can be controlled.

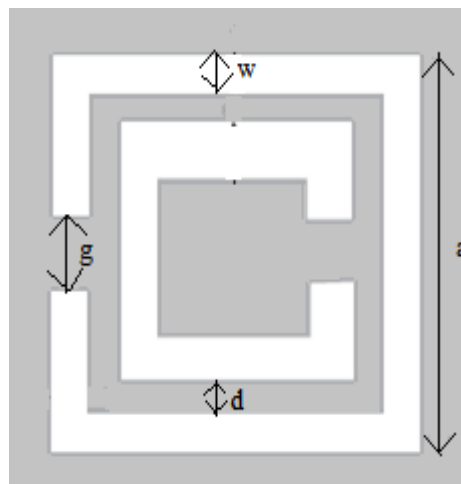


Fig. 3.11. Complementary Split Ring Resonator[6]

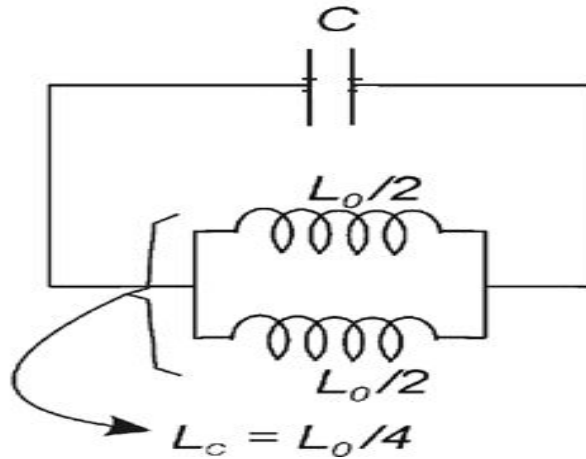
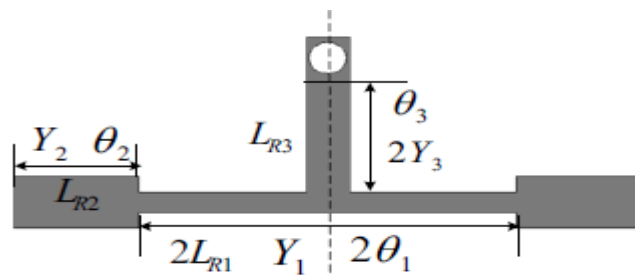


Fig. 3.12. Equivalent Circuit of CSRR[31]

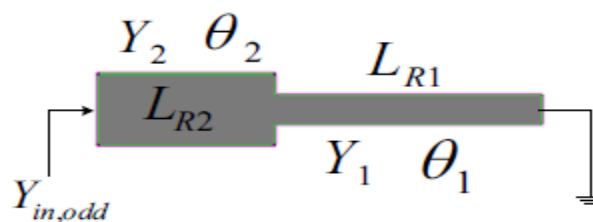
The main difference between SRR and CSRR is that in SRR negative-permeability is formed by etching series gaps in the conductor strip and forming series capacitance and in CSRR negative permittivity is formed by the use of shunt inductances [31]. CSRR is mainly the dual of SRR.

### 3.3 Stub Loaded Stepped Impedance Resonator

As we know that in SIR impedance is non-uniform, so there will be no perfect matching between the impedance. If impedances are not matched properly then there will be some reflection so there will be the formation of VSWR. VSWR can be improved by using stub on SIR. Centrally short stub loaded SIR is shown in Fig. 3.13(a)



(a)



(b)

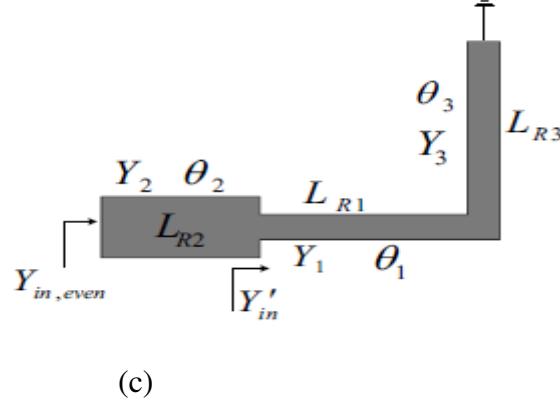


Fig. 3.13 (a) Configuration of the Proposed Shorted-stub Loaded SIR, (b) Odd-mode Equivalent Model, (c) Even-mode Equivalent Model [3]

Odd-even-mode equivalent model is illustrate in Fig. 3.13(b) and Fig. 3.13(c) This model is symmetrical in structure, odd-even-mode method can be used to analyze the resonant property.

For odd-mode excitation, the symmetrical plane is equivalent as short circuit, as shown in Fig. 3.13(b). The input admittance from the open end can be expressed as

$$Y_{in, odd} = Y_2 \frac{-jY_1 \cot \theta_1 + jY_2 \tan \theta_2}{Y_2 + Y_1 \cot \theta_1 \tan \theta_2} \quad (3.22)$$

When  $Y_{in, odd} = 0$ , the odd-mode resonant condition is derived as

$$\tan \theta_1 \tan \theta_2 = k \quad (3.23)$$

where,  $k = Y_1/Y_2$ . For simplicity, it is assumed that  $\theta_1 = \theta_2 = \theta$ , which substitutes into (3.23) then

$$\theta = \arctan \sqrt{k} \quad (3.24)$$

According to transmission line theory, odd-mode resonant frequency can be obtained as

$$f_{odd} = \frac{\arctan \sqrt{k} \cdot c}{2\pi L_{R1} \sqrt{\epsilon_e}} \quad (3.25)$$

Fig. 3.13(c) describes even-mode equivalent model, where the symmetrical plane is equivalent as open circuit. The input admittance can be expressed as

$$Y_{in, even} = Y_2 \frac{Y'_{in} + jY_2 \tan \theta_2}{Y_2 + jY'_{in} \tan \theta_2} \quad (3.26)$$

where,

$$Y'_{in} = Y_1 \frac{-jY_3 \cot \theta_3 + jY_1 \tan \theta_1}{Y_1 + Y_3 \cot \theta_3 \tan \theta_1} \quad (3.27)$$

Assume that  $Y_3=Y_1$ , by satisfying resonant condition  $Y_{in} = 0$  then value of  $k$  is

$$k = \frac{\tan \theta_2 \tan \theta_3 + \tan \theta_1 \tan \theta_2}{1 - \tan \theta_1 \tan \theta_3} \quad (3.28)$$

For simplicity, we assume  $\theta_1=\theta_2=\theta$ ,  $Y_3=Y_1$ . According to the even-mode resonant condition  $Y_{in, even} = 0$ , it can be derived

$$\tan(\theta+\theta_3)\tan\theta = k \quad (3.29)$$

Since  $\theta_3 \geq 0$ , the even-mode resonant frequency will shift towards lower frequency from odd-mode resonant frequency, which means

$$f_{even} \leq \frac{c}{2L_1\sqrt{\epsilon_{eff}}} = f_{odd} \quad (3.30)$$

At first, we design the SIR to put the odd mode frequency at the higher notched band, then optimize the length of shorted-stub to shift the even mode frequency to lower notched band.

### 3.4 Conclusion

In this chapter, triple notch band is obtained by using stepped impedance resonator and circular split ring resonator in UWB antenna. Quad notch band is obtained by using stepped impedance resonator, square split ring resonator and complementary split ring resonator in UWB antenna. The parameters of different resonators in the design are calculated mathematically according to the frequencies which are needed to be notched.

**NOTCHING OF UNDESIRED FREQUENCY BANDS BY DIFFERENT TYPES OF RESONATORS**

---

In recent times, increased awareness towards ultra wideband (UWB) communication system due to it has abundance of advantages. Different configurations of planar UWB antennas have developed with large bandwidth and easy fabrication for UWB applications. However, with the evolution of lots of modern wireless communication systems, numbers of narrow band wireless systems create interference in UWB as there frequency include in UWB frequency range. Narrow band wireless systems such as wireless local area network (WLAN) covers frequency bands of 2.4/5.8 GHz and worldwide interoperation for microwave access (WI-MAX) mainly in the frequency band around 3.5 GHz. International Telecommunications Union (ITU) has assigned the X band uplink frequency band (for sending modulated signals) as from 7.9 to 8.4 GHz. and downlink frequency band (for receiving signals) is from 7.25 to 7.75 GHz which are also creating interference in UWB. To resolve this difficulty, UWB antennas are loaded by different types of resonators. Although different antenna configurations are proposed, majority of them cannot produce more than two notch bands. In this chapter two configurations are shown, firstly a UWB antenna with SIR and Circular SRR along feed line to notch triple bands and secondly a UWB antenna with SIR and square SRR on feed line and CSRR on circular patch of antenna to notch quadruple bands. In these cases, a simple SIR is used but a conducting split will be there which provide short circuiting to one end of the SIR whereas the other end is open circuited.

**4.1 Principle of Operation for Implementing SIR along Feed Line**

A procedure of wave cancellation theory is used to establish single, double or multiple notch bands in ultra wideband antenna. In this procedure, a stepped impedance resonator is introduced having non uniform transmission line and different impedance. The spurious frequency and fundamental frequency are the frequencies at which resonance condition is to be satisfied. The number of notch bands can be determined by selecting the fundamental frequency and spurious frequency. If single notch band is essential then the SIR is not compulsory to resonate at spurious frequency. At the fundamental frequency, SIR will resonate and current will not reach to antenna and a stop band is obtained. If

multiple notch bands are required, SIR will resonate at those spurious frequencies. Antenna will reject those frequencies and multiple notch bands are obtained.

#### **4.2 Principle of Operation for Implementing SRR and CSRR**

SRR and CSRR working is based on metamaterial i.e. its properties cannot originate in nature having negative value of permeability and permittivity. Metamaterial shows how a signal moves in backward direction. By the equivalent LC circuit of SRR and CSRR we can find the resonant frequency. Current will not reach to antenna at resonant frequency and a stop band is obtained.

#### **4.3 Design Approach**

Fig. 4.1 shows the flow chart of resonators on UWB antenna design methodology. It indicates what the procedure are required to follow to get accurate design of resonators on UWB antenna.

#### **4.4 Triple Notch Bands in UWB by Using SIR and Circular SRR**

The geometry of the UWB circular monopole antenna is shown in Fig. 4.2 and the same antenna is loaded with different type of resonators for notching interfering bands. A monopole circular UWB antenna is created on substrate having,

Relative dielectric constant =3.48,

Loss tangent= 0 .004,

Thickness =1mm,

Length =52mm,

Width =43mm

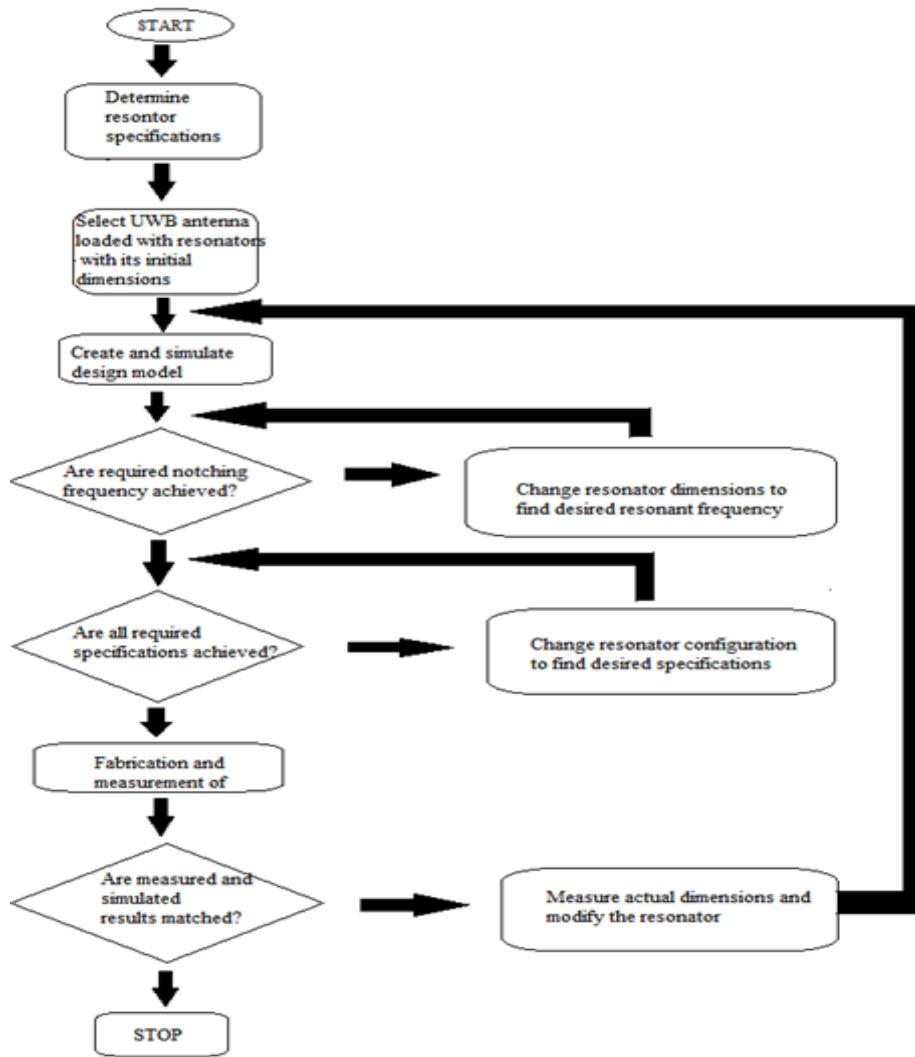


Fig. 4.1. Flow Chart of Resonator on UWB Antennas Design Methodology

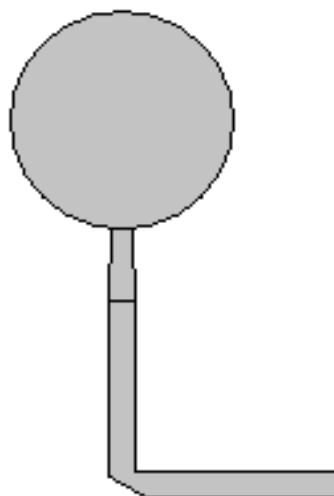


Fig. 4.2. Ultra Wideband

SIR and circular SRR are loaded on feed line of the planar circular monopole antenna to create triple notch band at desired frequencies. There is a conducting split to make one end of SIR ground and one end remains open. Fig. 4.3 shown below have SIR and SRR on feed line.

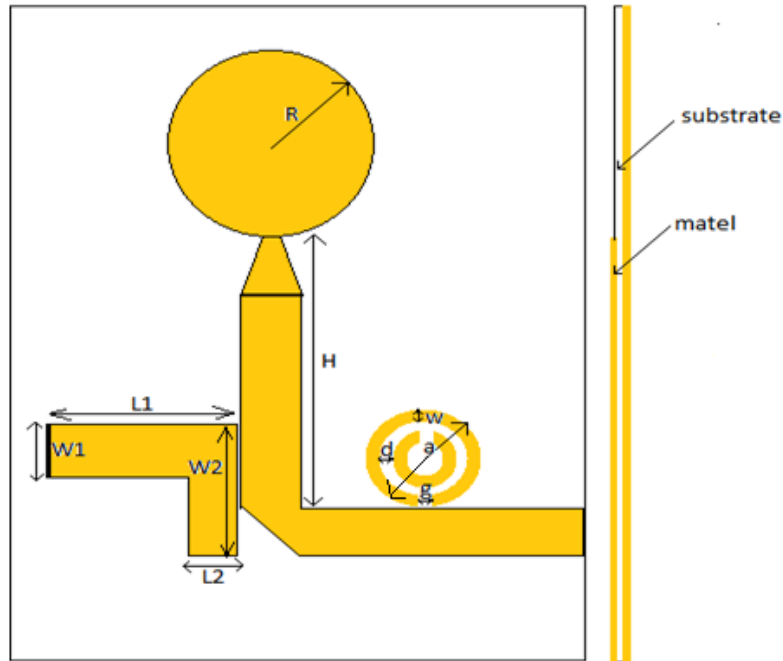


Fig. 4.3 Antenna with SIR and SRR Loaded along Feed Line

The return loss curve of circular monopole antenna is shown in Fig. 4.4 and it is found that the bandwidth of antenna lies in range 1.75GHz-10GHz thereby creating an UWB.

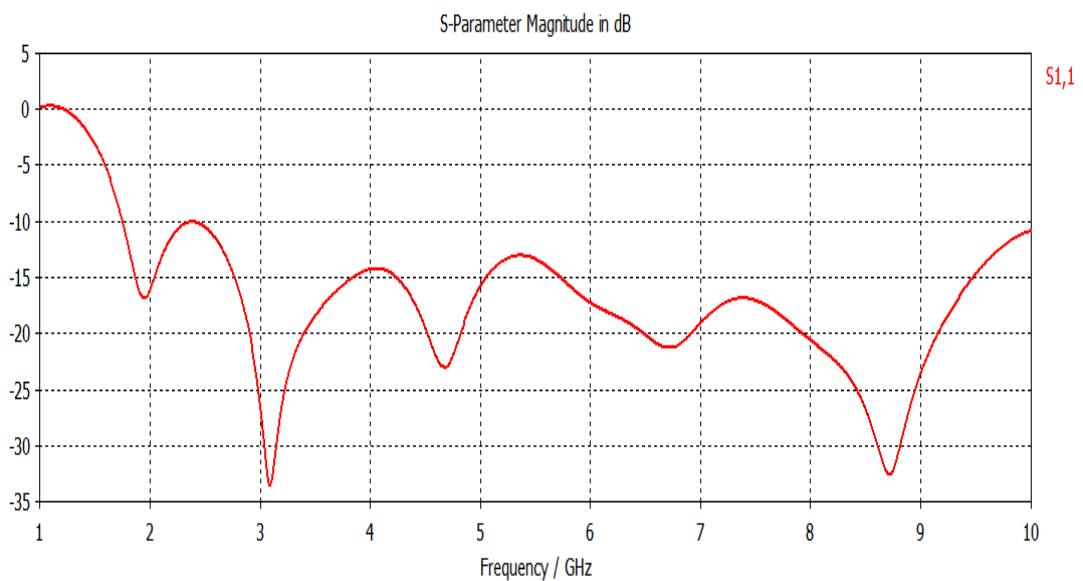


Fig. 4.4. Return Loss of Simple Circular Monopole Antenna

In order to study the effect of SIR and circular SRR on UWB antenna, a SIR and SRR are placed one by one and both SIR and SRR simultaneously along feed line.

The interfering bands are 2.4GHz, 3.5GHz and 5.8GHz. We want to notch these frequencies. In first case we want to notch 2.4GHz and 5.8GHz in UWB antenna. In this case, 2.4GHz is treated as fundamental frequency ( $f_0$ ) and 5.8GHz as spurious frequency ( $f_1$ ). So  $f_1/f_0 = 2.417$ . The value of  $R_z$  is found to be 1.72 using (3.7).

From (3.3), we have,

$$\tan\Theta_1 \tan\Theta_2 = 1.72$$

As the value of  $R_z$  is greater than 1, hence  $\Theta_1 + \Theta_2 > 90^\circ$ . From (3.3), the value of  $\Theta_1$  and  $\Theta_2$  are calculated to be  $59^\circ$  and  $46^\circ$  simultaneously, whose sum is equal to  $105^\circ$  i.e. greater than  $90^\circ$ . From (3.6), (3.10) and (3.11) the value of other parameters is calculated. Optimized parameters are shown in Table 1.

The proposed SIR along the left side of the feed as shown in the Fig. 4.5. The return loss curve is shown in Fig. 4.6.

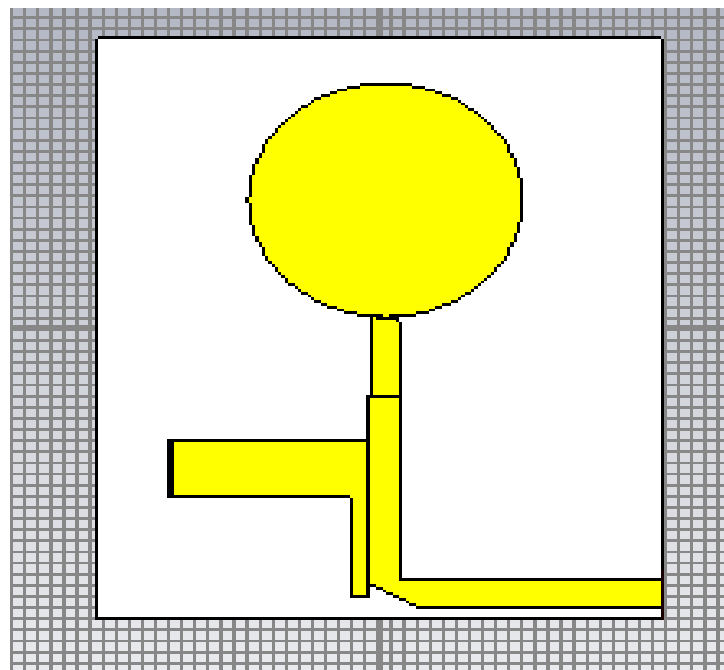


Fig. 4.5. Antenna with SIR on Left Side of the Feed Line

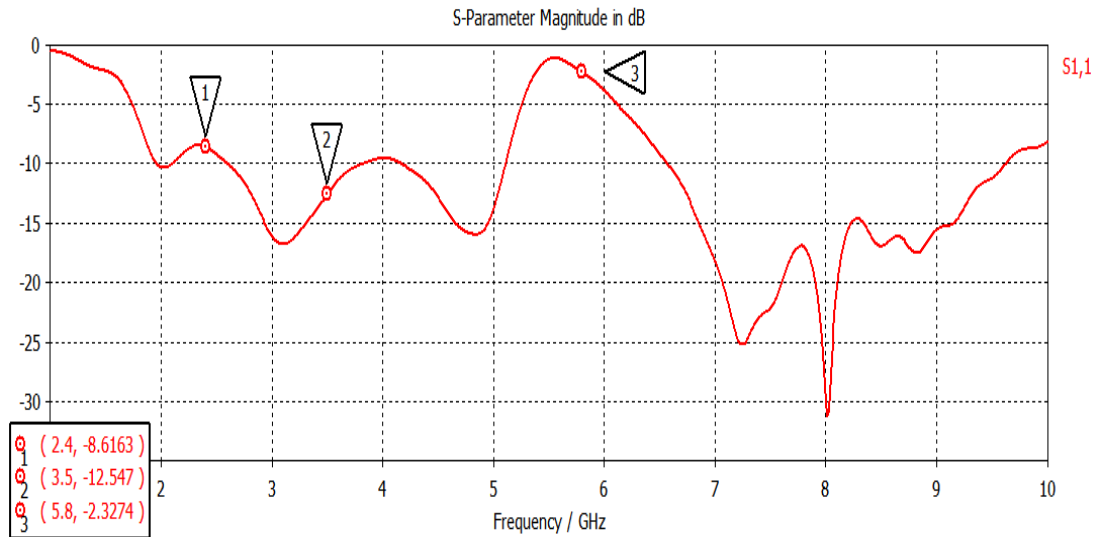


Fig. 4.6. Return Loss i.e. S11 Parameter of Antenna with SIR on Left Side of the Feed Line

From curve it has been observed at 2.4, 3.5 and 5.8GHz the values of return loss are -8.6163dB, -12.547dB and -2.3274dB respectively. It is observed that a pass band is obtained at 3.5GHz which is below -10dB, so it will create interference whereas 2.4, 5.8 GHz frequencies are rejected.

Now in second case, we want to reject 3.5GHz in UWB antenna. For this a SRR is used which is in the right side of feed line. Resonant frequency is calculated by (3.15). Radius of outer ring of SRR is 4.44mm, gap is 0.2mm, radius of ring is 0.2 mm and radius of free space between two rings is 0.2 mm. These all dimensions are calculated by formulas which are described in chapter 3. Optimized dimensions are given in table 1. In this it will reject 3.5GHz having return loss of -5.3113dB. The proposed circular SRR along the left side of the feed as shown in the Fig. 4.7. The return loss curve is shown in Fig. 4.8.

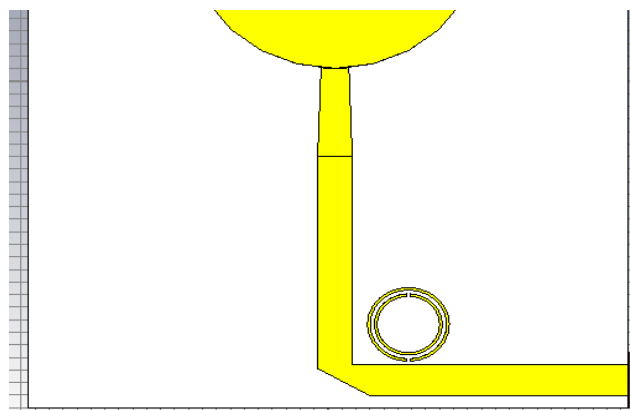


Fig. 4.7. Antenna with SRR on Right Side of the Feed Line

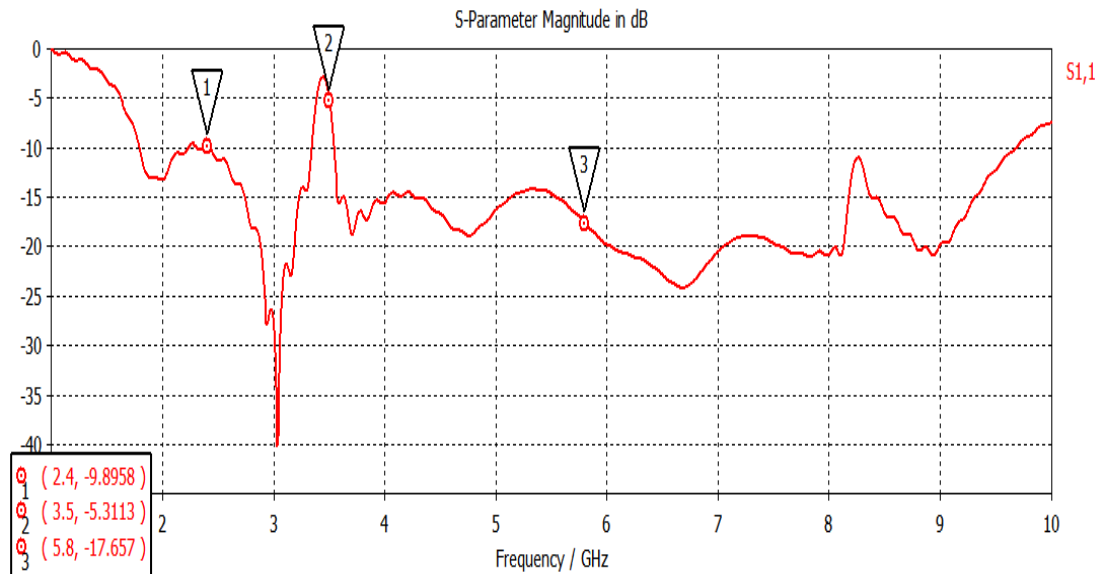


Fig. 4.8 Return Loss i.e. S11 Parameter of Antenna with SRR on Right Side of the Feed Line

From curve it has been observed at 2.4, 3.5 and 5.8GHz the values of return loss are -9.8958dB, -5.3113dB and -17.657dB respectively. It is observed that pass bands are obtained at 2.4GHz and 5.8GHz which is below -10dB, so it will create interference whereas 3.5 GHz frequencies is rejected.

Now lastly, a SIR is connected on left side of feed line and SRR is on right side of feed line as shown in Fig. 4.9 and 2.4, 3.5, and 5.8GHz frequencies are all rejected as shown in Fig. 4.10.

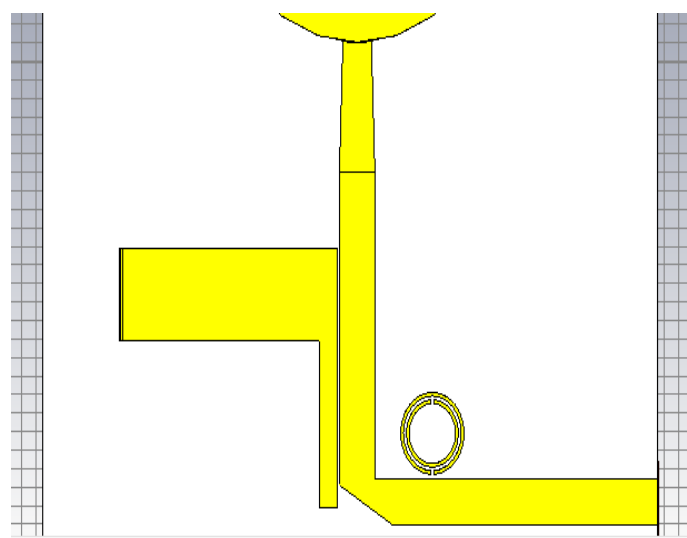


Fig. 4.9 Antenna with SIR and SRR on the Feed Line

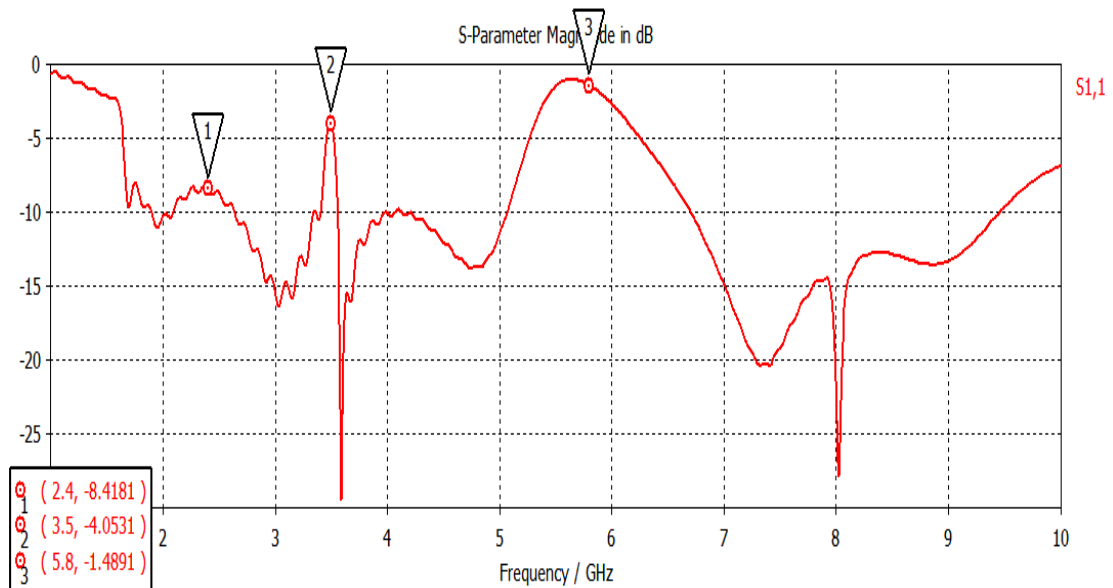


Fig. 4.10 Return Loss i.e. S11 Parameter of Antenna with SIR and SRR on the Feed Line

From curve it has been observed at 2.4, 3.5 and 5.8GHz the values of return loss are -8.4181dB, -4.0531dB and -1.4891dB respectively. Notching of triple bands is obtained.

Voltage Standing Wave Ratio curve is shown in Fig. 4.11.

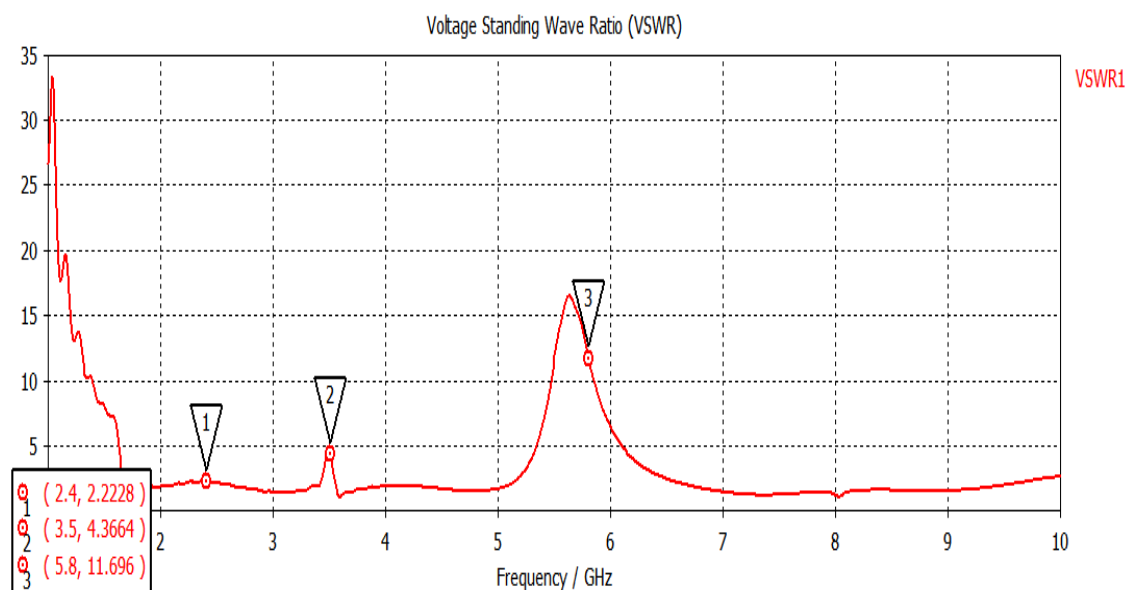


Fig. 4.11. Voltage Standing Wave Ratio

From curve it is observed that at 2.4GHz, 3.5GHz and 5.8GHz value of VSWR is greater than 2.

Table 4.1 Parameters and its Optimized Value

Parameter	R	H	$L_1$	$L_2$	$W_1$
Value(mm)	10.5	26	15.13	1.25	5
Parameter	$W_2$	A	d	g	w
Value(mm)	14	4.44	.2	.2	.2

Table 4.2 Comparison of Return Loss Values at Various Frequencies with Conditions of SIR and SRR

Notch Frequencies (in GHz)	SIR on the left side of the feed line (in dB)	SRR on the right side of the feed line (in dB)	SIR and SRR on feed line (in dB)
2.4	-8.6163	-9.8958	-8.4181
3.5	-12.547	-5.3113	-4.0531
5.8	-2.3274	-17.657	-1.4891

#### 4.5 Quadruple Notch Bands in UWB by Using SIR, Square SRR and CSRR

First of all, a UWB circular monopole antenna is designed on a substrate having relative dielectric constant 3, loss tangent of 0.001, and thickness of 1 mm, with length and width of 52 mm and 47 mm, respectively. Now this antenna is loaded with SIR, SRR on feed line and CSRR on circular patch for notching the interfering frequencies in UWB. A tapered line is used for matching the impedance between antenna and notch band filter [8]. The proposed antenna with different resonators is shown in Fig. 4.12.

A UWB antenna is designed with frequency range of 1.85GHz to 10GHz thereby generating wide band. The proposed antenna and its return loss curve are shown in Fig. 4.13 and Fig. 4.14.

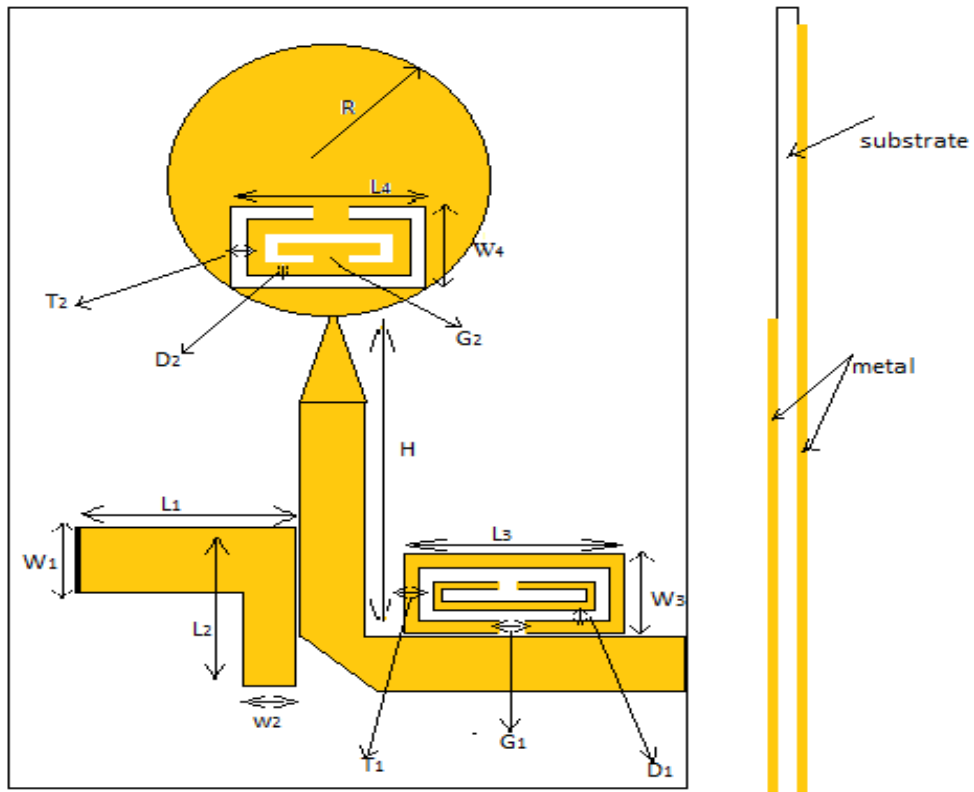


Fig. 4.12. Configuration of Proposed Antenna

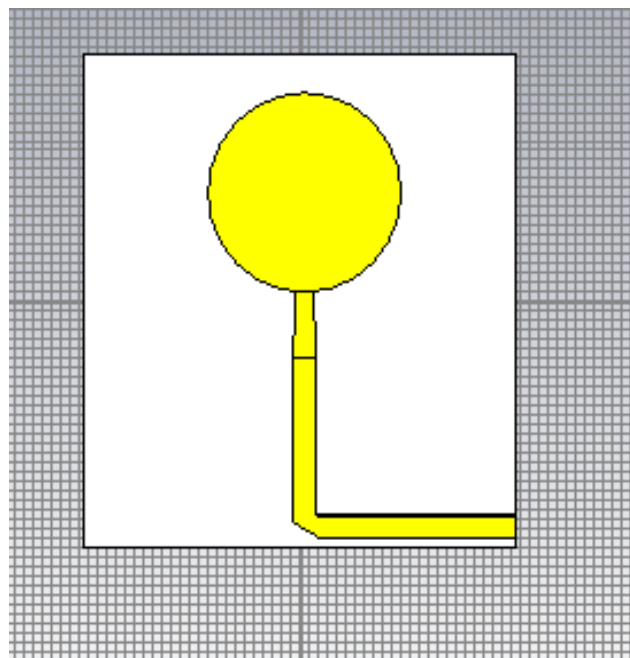


Fig. 4.13. Circular Monopole Antenna

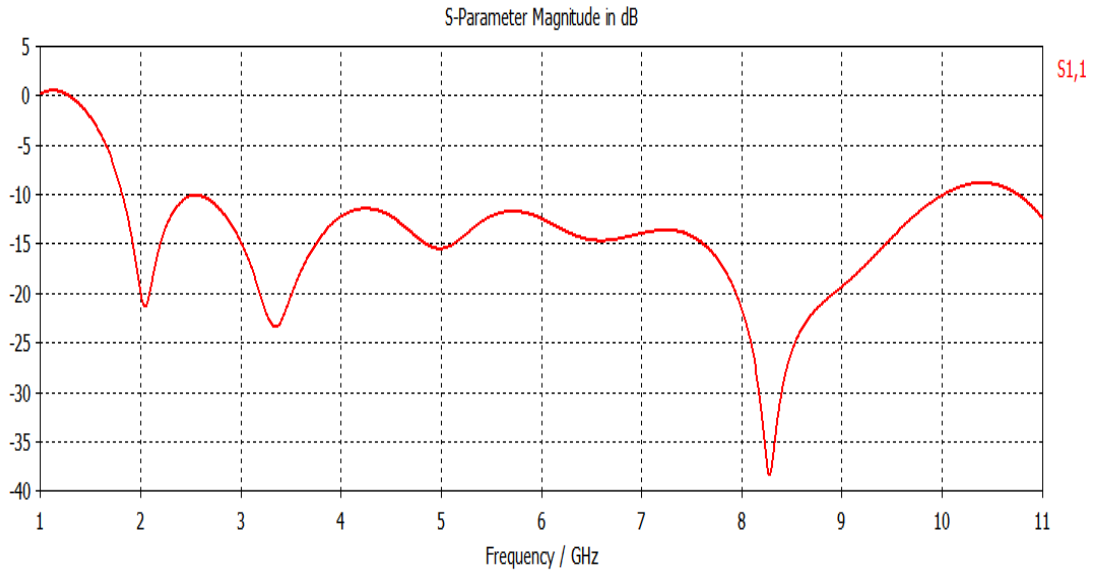


Fig. 4.14. Simulated S11 Parameter of Circular Monopole Antenna

From Fig. 4.14 it is observed that from 1.85 GHz to 10GHz all frequencies are passed but there are some frequencies which interfere in this range. We want to notch 2.4GHz, 3.5GHz, 5.8GHz and 8.4GHz frequencies.

With the help of SIR 2.4GHz and 5.8GHz frequencies are notched. The fundamental frequency is 2.4GHz and spurious frequency is 5.8GHz. Above given equation (3.7) of SIR, impedance ratio is calculated which is 1.72 and from this impedance ratio other parameters are calculated from chapter 3. Optimized parameters are defined in Table 3.

A conducting split is formed on SIR to provide short circuit to one end. This SIR is placed on left side of feed line as shown in Fig. 4.15.

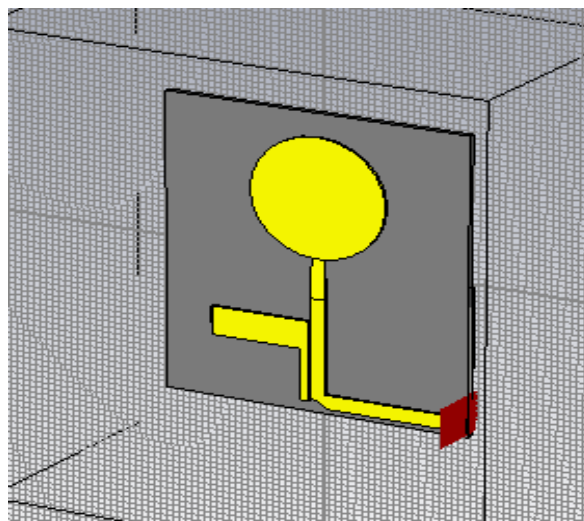


Fig. 4.15 Circular Monopole Antenna with SIR

The return loss curve of UWB antenna when SIR is used is shown in Fig. 4.16.

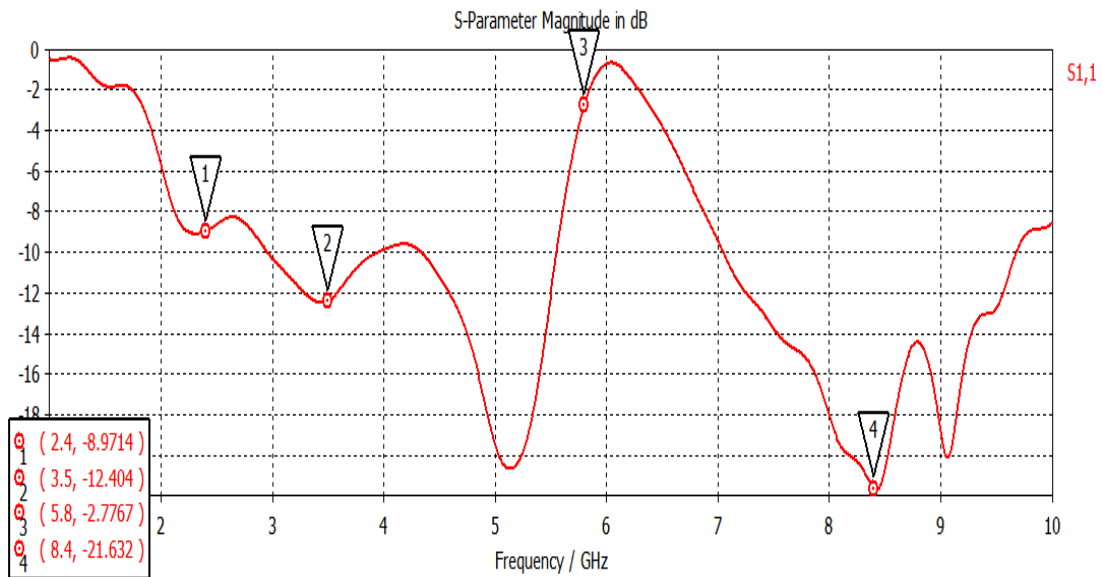


Fig. 4.16. Simulated S11 Parameter of Circular Monopole Antenna with SIR

From Fig. 4.16 it is observed that 2.4GHz and 5.8GHz frequencies are stopped and other are passed.

SRR is used to notch 3.5GHz frequency. It forms a LC equivalent circuit. The resonant frequency can be calculated by (3.15) and all other parameters are also calculated. Optimizes parameters are defined in Table 3. SRR is placed on right side of feed line as shown in Fig. 4.17.

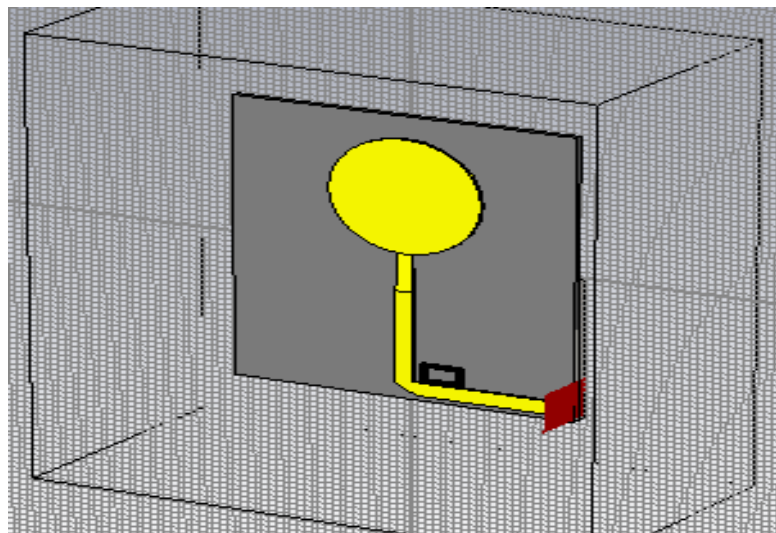
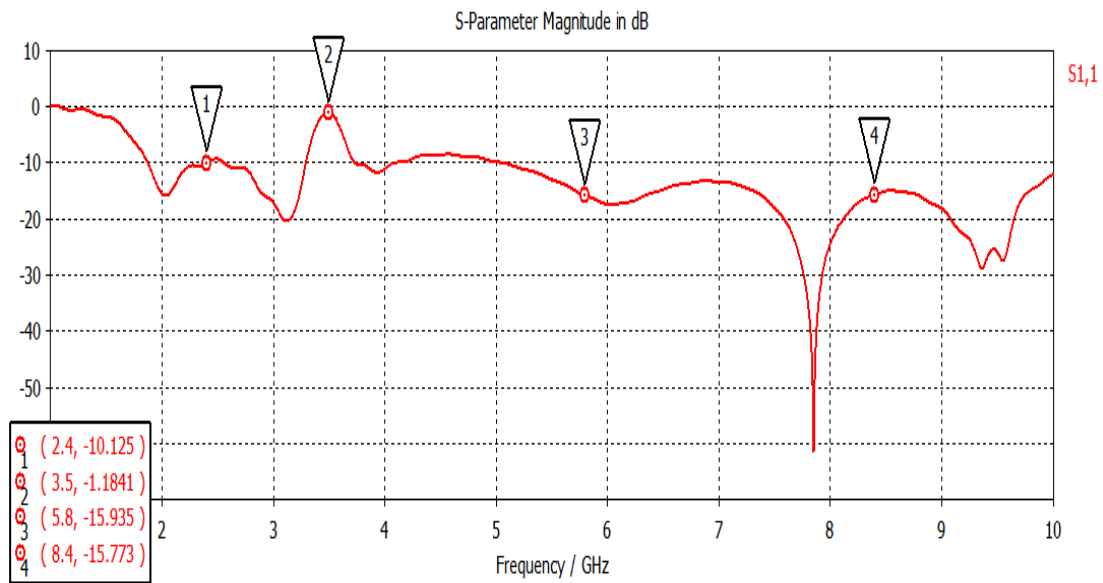


Fig. 4.17 Circular Monopole Antenna with SRR

Return loss curve of UWB antenna when SRR is used is shown in Fig. 4.18.



Fig

#### 4.18 Simulated S11 Parameter of Circular Monopole Antenna with SRR

From Fig. 4.18 it is clear that SRR is rejecting 3.5GHz frequency and all other frequencies are passed.

CSRR is used to notch 8.4GHz frequency. The structure of CSRR is counterpart of SRR having LC equivalent circuit resonant frequency can be calculated as (3.21). By determining L and C other parameters are calculated. Optimized parameters are defined in Table 3. CSRR is on the circular patch as shown in Fig. 4.19.

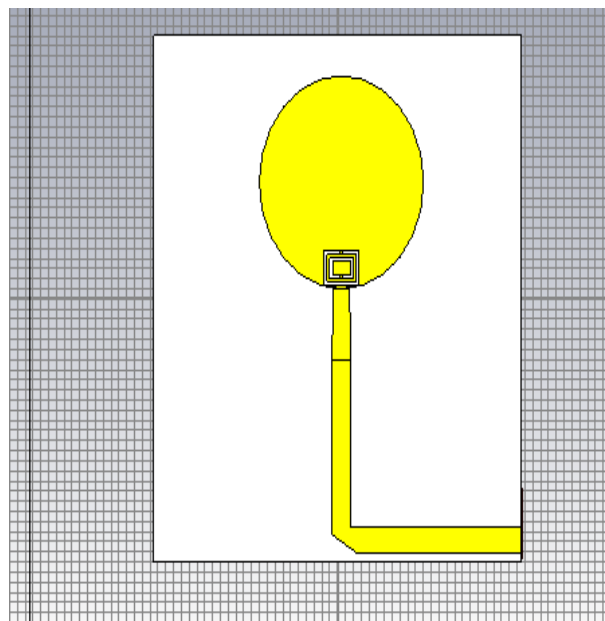


Fig. 4.19. Circular Monopole Antenna with SRR

Return loss curve of UWB antenna when CSRR is used is shown in Fig. 4.20.

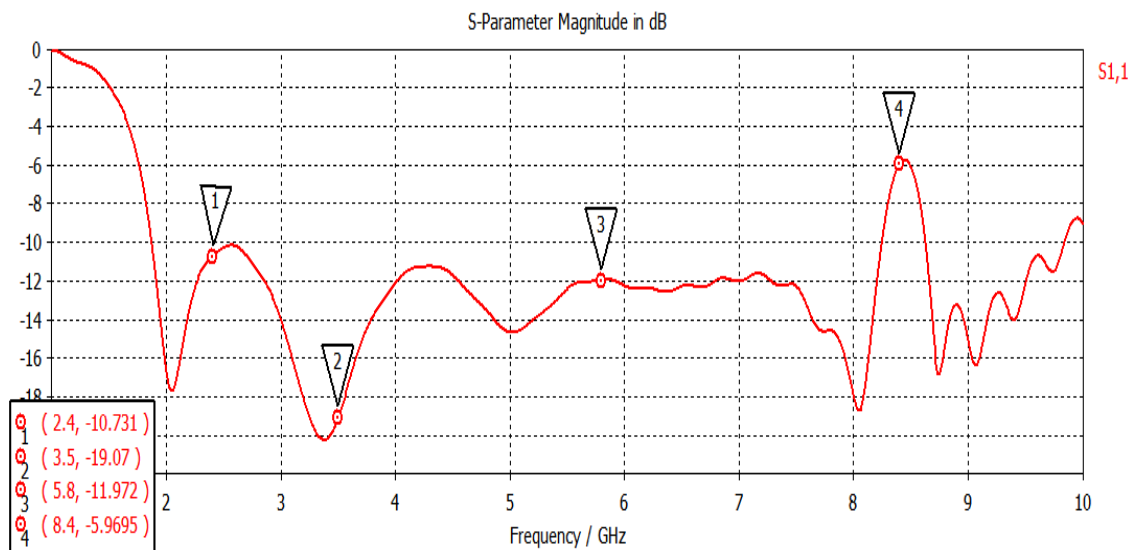


Fig. 4.20. Simulated S11 Parameter of Circular Monopole Antenna with CSRR

From Fig. 4.20 it is observed only 8.4GHz frequency is notched and other frequencies are passed.

A UWB antenna with SIR, SRR and CSRR is shown in Fig. 4.21.

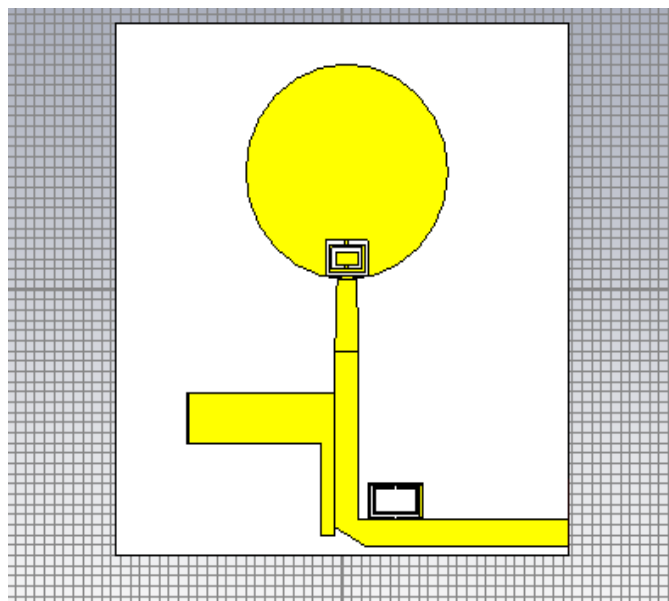


Fig. 4.21 Circular Monopole Antenna with SIR, SRR and CSRR

Return loss curve of UWB antenna when SIR, SRR and CSRR are used is shown in Fig. 4.22.

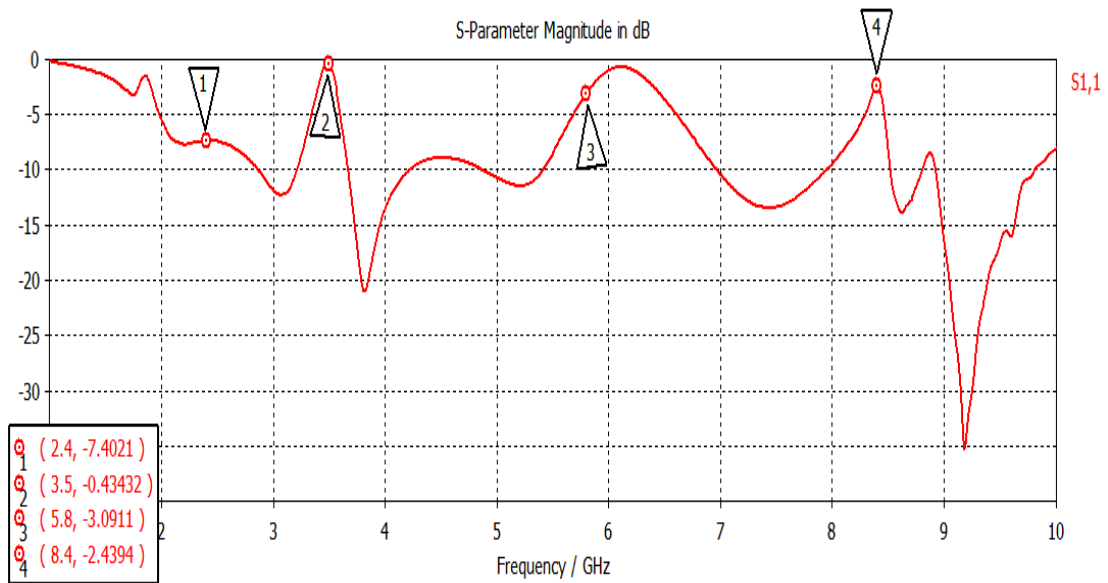


Fig. 4.22 Simulated S11 Parameter of Circular Monopole Antenna with SIR, SRR and CSRR

From curve it is observed that 2.4GHz, 3.5GHz, 5.8GHz and 8.4GHz frequencies are rejected from UWB.

VSWR curve is shown in Fig. 4.23.

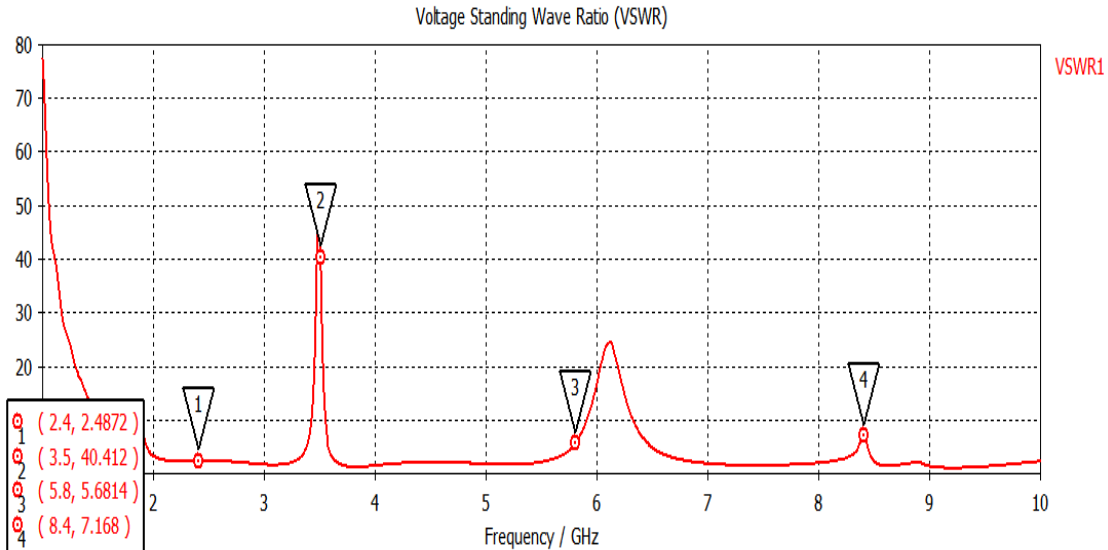


Fig. 4.23. Voltage Standing Wave Ratio Curve

From curve it is observed that at 2.4GHz, 3.5GHz, 5.8GHz and 8.4GHz value of VSWR is greater than 2.

Table 4.3 Different Parameters and its Optimized Values

Parameter	R	L <sub>1</sub>	L <sub>2</sub>	W <sub>1</sub>	W <sub>2</sub>	L <sub>3</sub>	W <sub>3</sub>	T <sub>1</sub>
Value(mm)	10.5	15.13	14	5	1.25	5.5	3.5	.2
Parameter	H	G <sub>1</sub>	D <sub>1</sub>	T <sub>2</sub>	G <sub>2</sub>	D <sub>2</sub>	L <sub>4</sub>	W <sub>4</sub>
Value(mm)	26	.4	.2	.4	.4	.3	4.5	3.5

Table 4.4 Comparison of Return Loss at Various Frequencies with Different Resonators

Notch Frequencies (in GHz)	SIR on the left side of the feed (in dB)	SRR on the right side of the feed (in dB)	CSRR on the circular patch (in dB)	SIR , SRR and CSRR on UWB antenna(in dB)
2.4	-8.9713555	-10.140676	-10.730964	-3.0911319
3.5	-12.40356	-1.1739775	-19.069613	-0.43431865
5.8	-2.7766738	-15.940869	-11.972215	-7.4020682
8.4	-21.632007	-15.773456	-5.96948	-2.4394446

#### 4.6 Conclusion

In this chapter, triple band rejection is designed and simulated using SIR and SRR on UWB antenna. Quadruple band rejection is also designed and simulated using SIR, SRR and CSRR on UWB antenna. It has been observed that the value of return loss is above -10dB and VSWR is greater than 2 at notching frequencies.

## CHAPTER 5

### REJECTION OF QUADRUPLE UNDESIRED FREQUENCIES BY USE OF STUB LOADED SIRs

In this chapter, quadruple band rejection is obtained by the using stub loaded stepped impedance resonators for filtering the undesired frequencies in UWB antenna. The antenna with Stub loaded SIR is designed and simulated in this chapter. The design of UWB antenna is same as in chapter 4. SIR with stub is used to for impedance matching so that there is no reflection of waves that means there is improvement in VSWR. At notching frequencies VSWR is greater than 2 and at all other frequencies VSWR is less than 2. The notching frequencies are 2.4GHz, 3.5GHz, 5.8GHz and 7.5GHz. The advantage of using stub loaded SIR is that it has the capability to independently tune two frequencies. It has a compact size and easy implementation on the UWB antenna.

#### 5.1 Design of Ultra Wide Band with Stub Loaded SIR

The UWB circular monopole antenna is connected with stub loaded stepped impedance resonators along both side of the feed line as shown in Fig. 5.1. The antenna has dielectric constant -3.48, thickness -.802mm, width - 41mm and length – 50mm

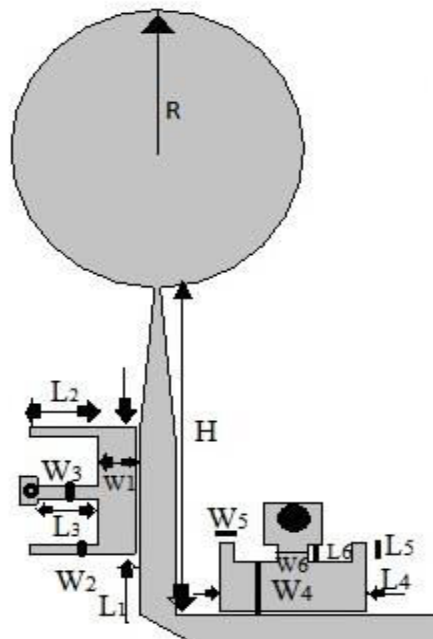


Fig. 5.1. UWB antenna with stub loaded SIR

As we know that SIR has non uniform impedance so there is no matching of impedance. A short circuit stub is loaded on SIR to provide impedance matching so that there is improvement in VSWR.

First of all, a UWB monopole antenna is designed as shown in Fig. 5.2 and its return loss curve is shown in Fig. 5.3.

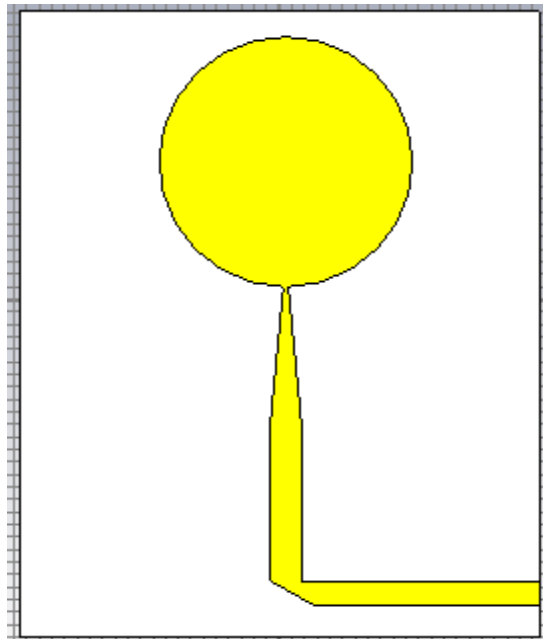


Fig. 5.2. Ultra Wide Band Antenna

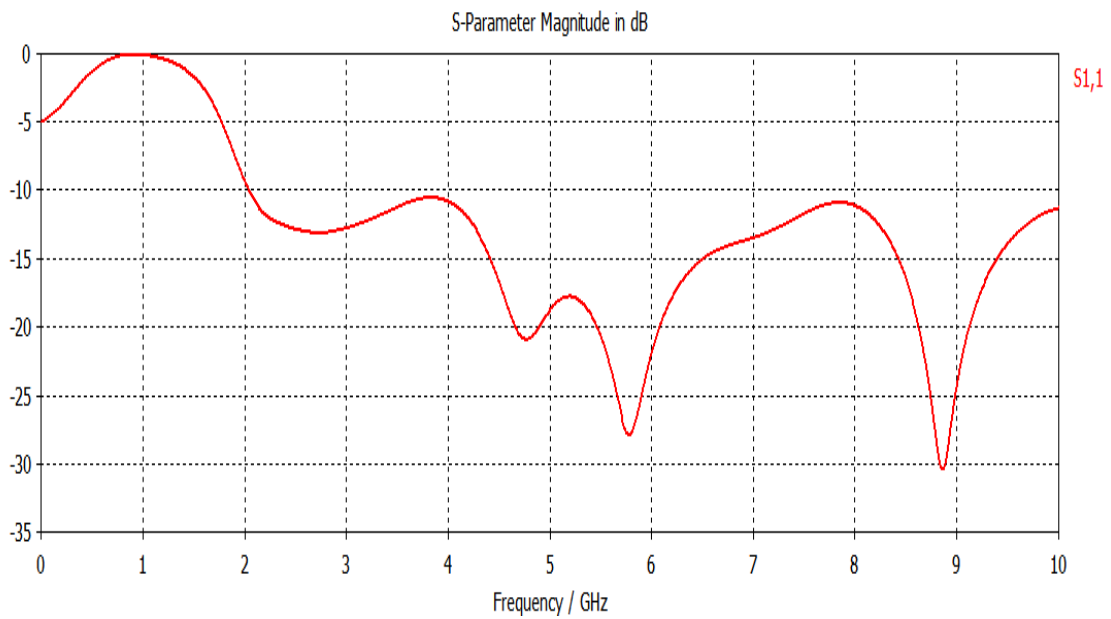


Fig. 5.3. Return Loss Curve of UWB Antenna

From Fig. 5.3 it is observed that a UWB antenna's frequency range is from 2GHz to 10GHz. From 2 GHz to 10GHz S<sub>1,1</sub> value is below -10dB. As frequency range is too wide so it is named as Ultra Wideband.

Now, we want to reject frequencies 2.4 and 5.8GHz by the use of stub loaded SIR which is connected left side of feed line of UWB antenna as shown in Fig. 5.4. Here we have selected the value of admittance ratio  $k$  which is equal to .25. From equation (3.23) and (3.28) other dimensions are also calculated. Optimized parameters are listed below  $L_1 = 9.2\text{mm}$ ,  $L_2 = 4.74\text{mm}$ ,  $L_3 = 7.99\text{mm}$ ,  $W_1 = 2.56\text{mm}$ ,  $W_2 = .7\text{mm}$  and  $W_3 = 1\text{mm}$ .

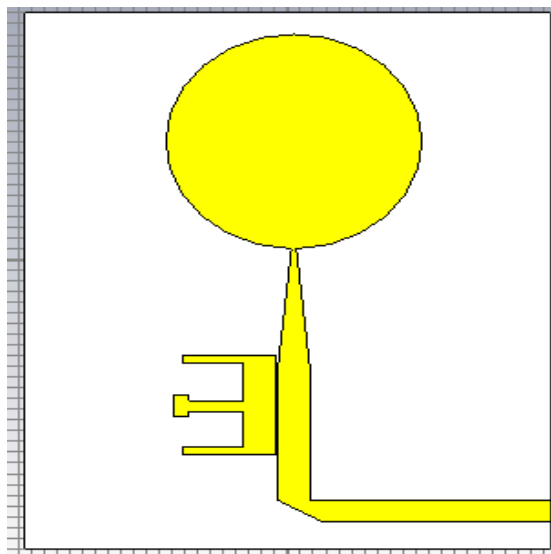


Fig. 5.4. UWB Antenna with Stub Loaded SIR on the Left Side of Feed Line

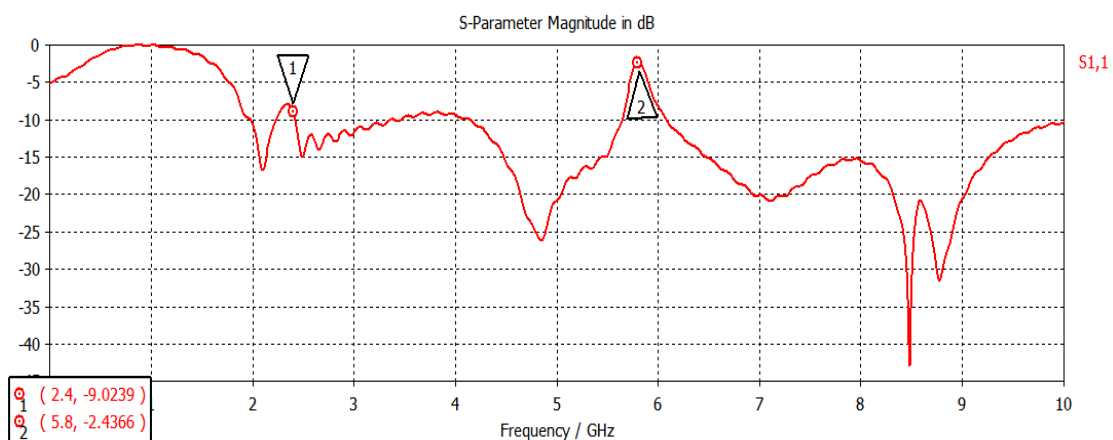


Fig. 5.5 Return Loss Curve of UWB Antenna with Stub Loaded SIR on the Left Side of Feed Line

From Fig. 5.5 it is observed that at frequencies 2.4GHz and 5.8GHz  $S_{1,1}$  value is above -10dB it means that these frequencies are rejected and all other frequencies are passed.

Next step is to reject 3.5GHz and 7.5GHz frequencies by integrating stub loaded on the right side of feed line of UWB antenna as shown in Fig. 5.6. The selected admittance ratio is .16. From equation (3.23) and (3.28) other dimensions are also calculated. Optimized parameters are listed below

$L_4 = 10\text{mm}$ ,  $L_5 = 1.4\text{mm}$ ,  $L_6 = 7.8\text{mm}$ ,  $W_4 = 3.6\text{mm}$ ,  $W_5 = 1\text{mm}$  and  $W_6 = 2\text{mm}$ .

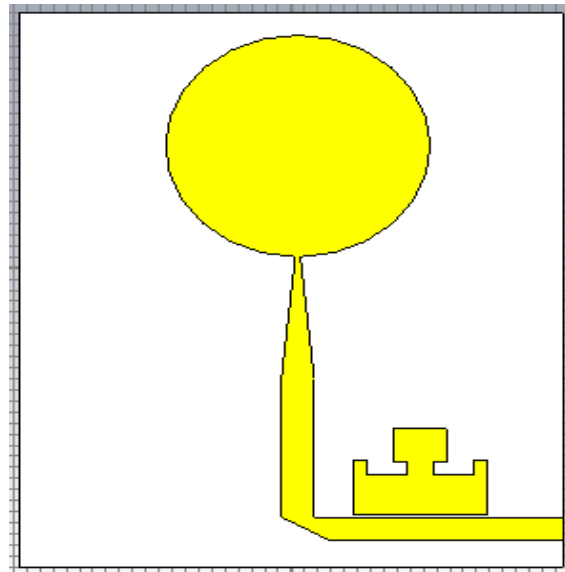


Fig. 5.6 UWB antenna with Stub Loaded SIR on the Right Side of Feed Line

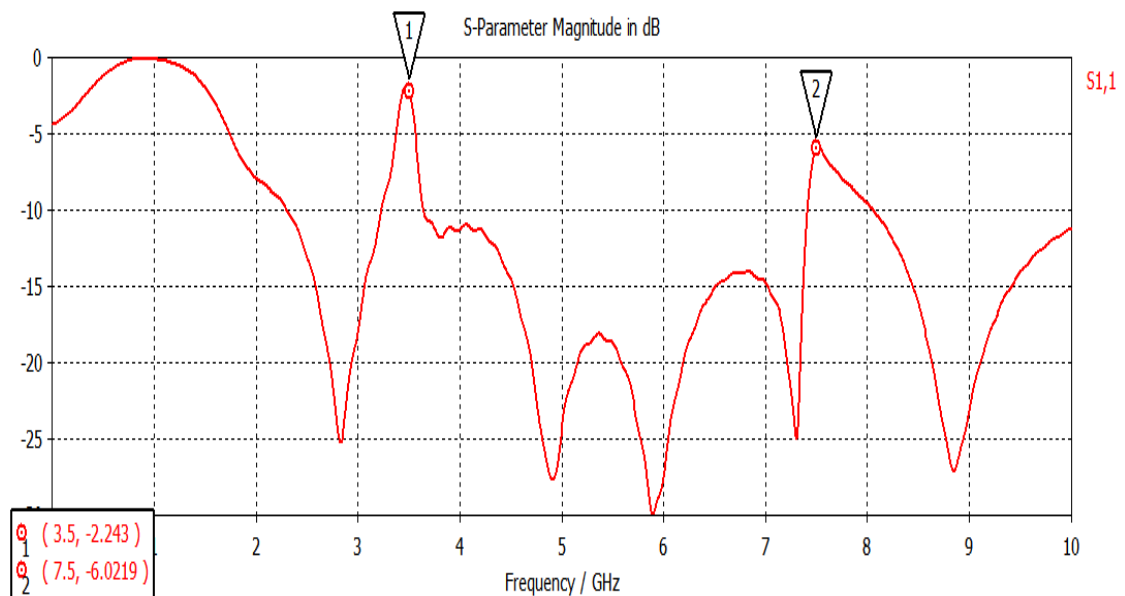


Fig. 5.7 Return Loss Curve of UWB Antenna with Stub Loaded SIR on the Right Side of Feed Line

From Fig. 5.7 it is observed that at frequencies 3.5GHz and 7.5GHz S<sub>1,1</sub> value is above -10dB it means that these frequencies are rejected and all other frequencies are passed.

Both SIRs are connected to UWB antenna to reject 2.4GHz, 3.5GHz, 5.8GHz and 7.5GHz. Integrated SIRs on UWB antenna is shown in Fig. 5.8.

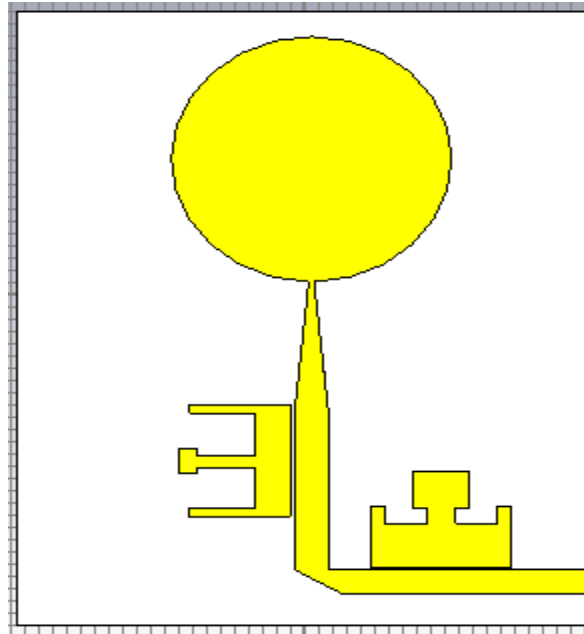


Fig. 5.8. UWB Antenna with Stub Loaded SIRs Along Feed Line

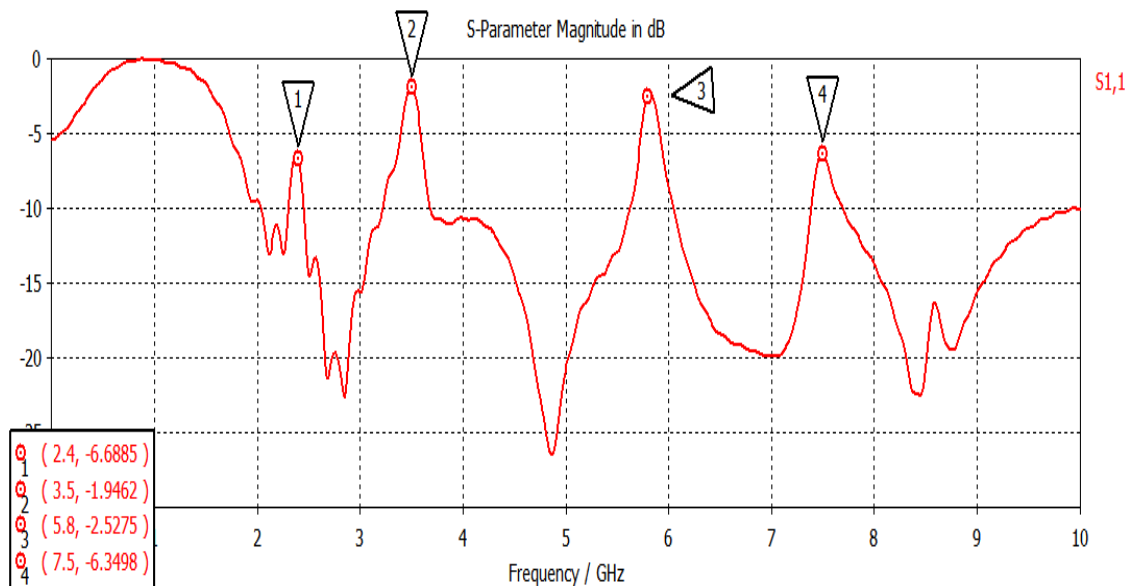


Fig. 5.9 Return Loss Curve of UWB Antenna with Stub Loaded SIRs along Feed Line

From Fig. 5.9 it is observed that at frequencies 2.4GHz, 3.5GHz, 5.8GHz and 7.5GHz S1,1 value is above -10dB it means that these frequencies are rejected and all other frequencies are passed.

Table 5.1 Comparison of Return Loss Values at Various Frequencies with Conditions of SIRs

Notch Frequencies (in GHz)	Stub loaded SIR on the left side of the feed (in dB)	Stub loaded SIR on the right side of the feed (in dB)	Stub loaded SIRs on the both side of the feed (in dB)
2.4	-9.0239	-11.089	-6.6885
3.5	-9.5799	-2.243	-1.9462
5.8	-2.43669	-25.5702	-2.5275
7.5	-17.5292	-6.0219	-6.3498

Stub is used to remove reflected wave i.e. impedance matching is done by short circuit stub on SIR. At frequencies 2.4GHz, 3.5GHz, 5.8GHz and 7.5GHz value of VSWR is greater than 2 ( $VSWR > 2$ ) and at rest frequencies value of VSWR is smaller than 2 ( $VSWR < 2$ ) which is shown in Fig. 5.10.

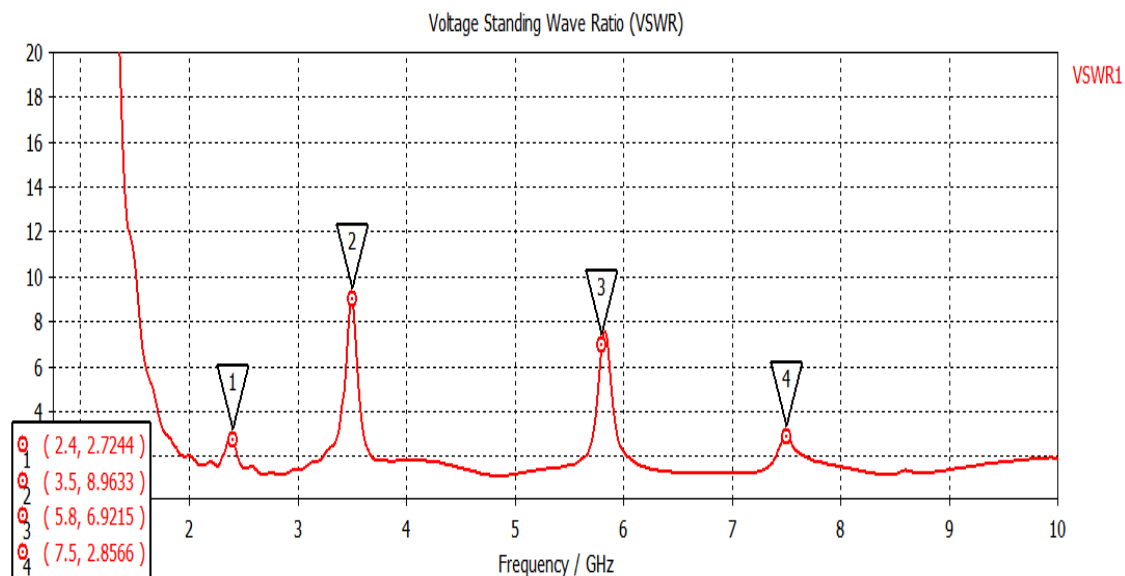


Fig. 5.10 VSWR Curve When SIRs are Connected to UWB Antenna

Current distribution at different frequencies is shown from Fig. 5.11 to Fig. 5.14. At these resonant frequencies current does not reach at antenna and it is stopped by stub loaded stepped impedance resonators.

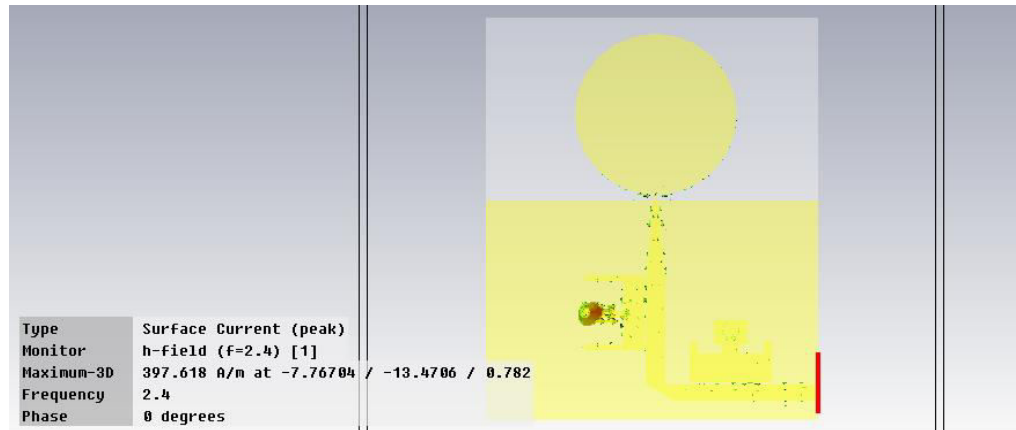


Fig. 5.11 Current Distribution of Antenna with Stub Loaded SIRs at 2.4GHz

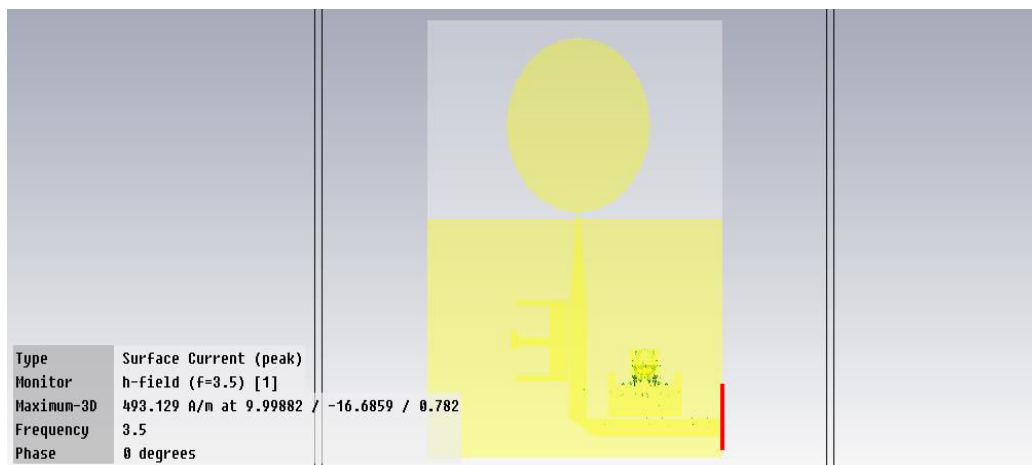


Fig. 5.12 Current Distribution of Antenna with Stub Loaded SIRs at 3.5GHz

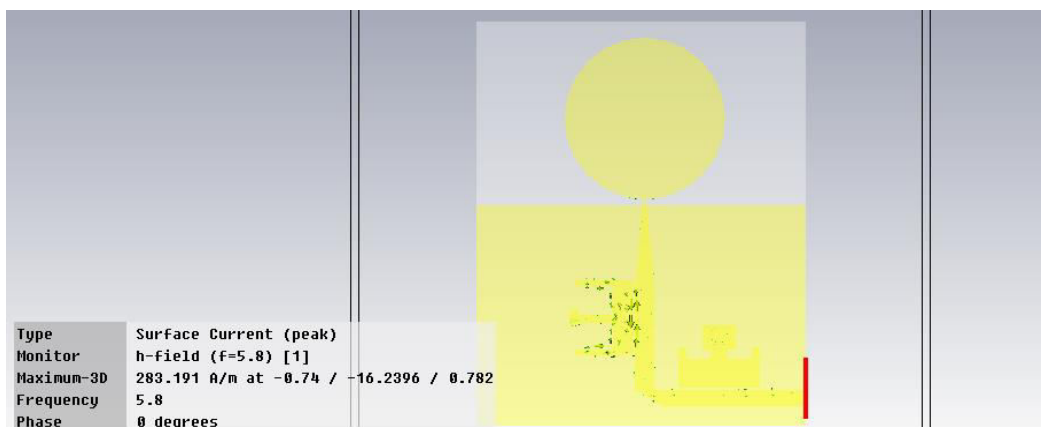


Fig. 5.13 Current Distribution of Antenna with Stub Loaded SIRs at 5.8GHz

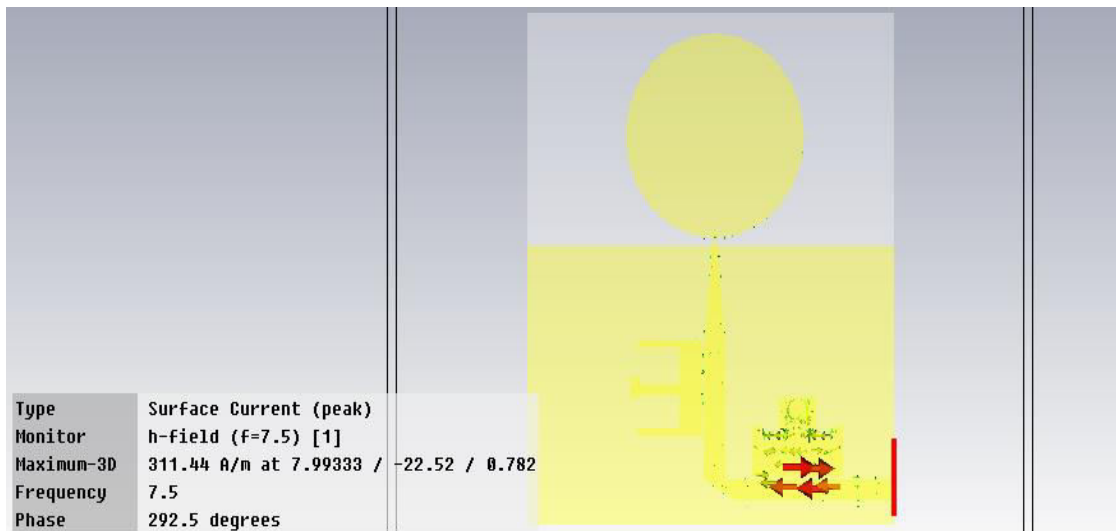


Fig. 5.14 Current Distribution of Antenna with Stub Loaded SIRs at 7.5GHz

## 5.2 Fabricated Antenna with Stub Loaded SIRs

The circular monopole antenna integrated with stub loaded SIRs is shown in Fig. 5.15 and Fig. 5.16. The top view of antenna is shown in Fig. 5.15 and bottom view of antenna is shown in Fig. 5.16 Roger 4350 is used with thickness of .802mm. The height of the PEC material is .02mm.

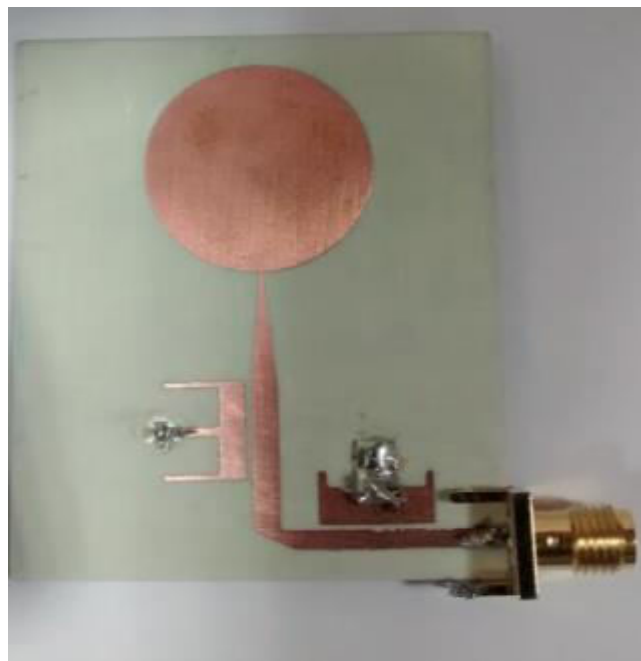


Fig. 5.15 Top View of the Antenna with Stub Loaded SIRs



Fig. 5.16 Bottom View of the Antenna with Stub Loaded SIRs

### 5.3 Testing using VNA

The simulated antenna is tested using VNA model no.N5222A which is shown in Fig. 5.17. Its frequency range lies between 10MHz to 26.5GHz.



Fig. 5.17 VNA Model no. N5222A

## 5.4 Simulated Result

Simulated result is obtained by using CST Studio 2010 is shown in Fig. 5.18. This antenna is fabricated and its result is obtained by using VNA. VNA result is shown in Fig. 5.19.

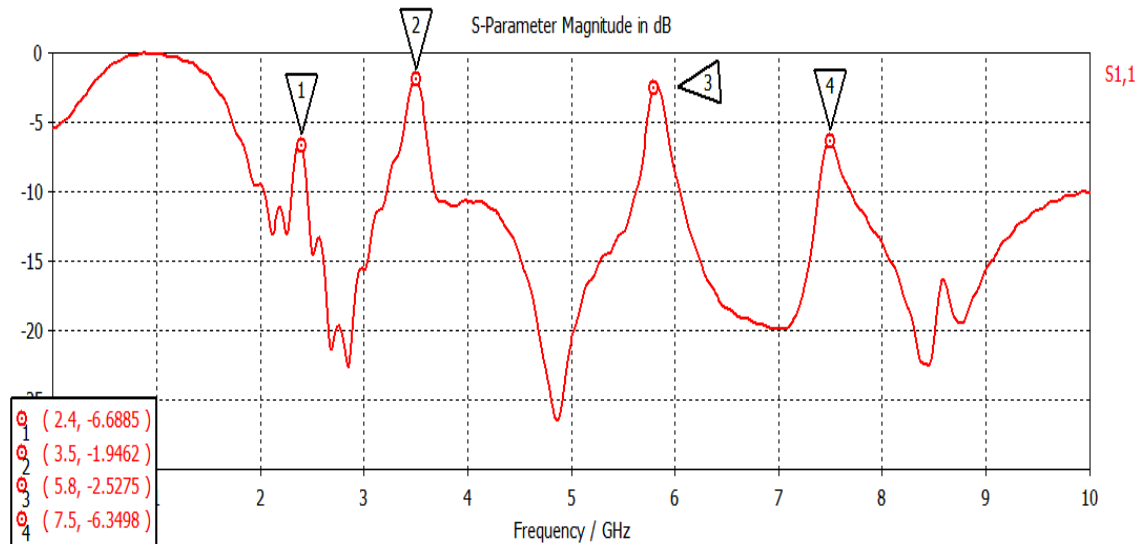


Fig. 5.18 Simulated Result of Stub Loaded SIRs on UWB Antenna Using CST Studio 2010.

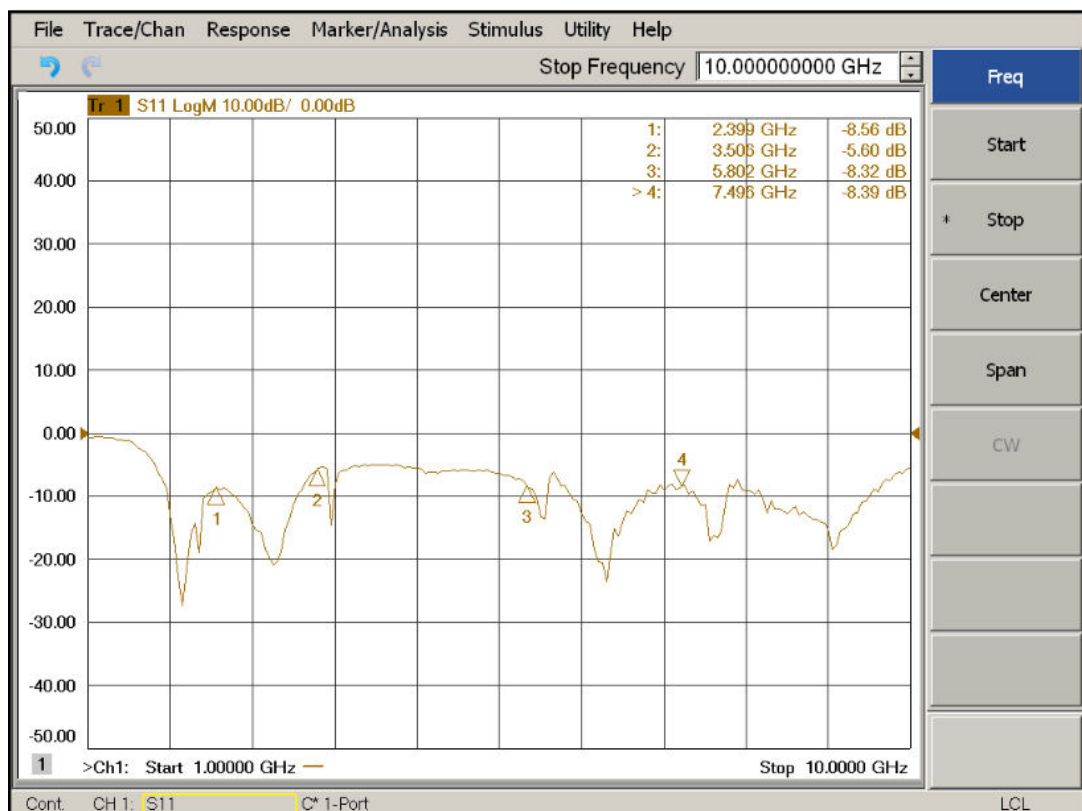


Fig. 5.19 Measured Result of Stub Loaded SIRs on UWB Antenna Using VNA

Table 5.2 Comparison between the Simulated and Measured Result at Various Frequencies

Frequencies(GHz)	S <sub>11</sub> parameter in dB (Simulated)	S <sub>11</sub> parameter in dB (Measured)
2.4	-6.6885	-8.56
3.5	-1.9462	-5.60
5.8	-2.5275	-8.32
7.5	-6.3498	-8.39

### 5.5 Conclusion

In this chapter, quadruple band rejection is designed and simulated using stub loaded SIR along the feed line of circular monopole antenna. It has been observed that the value of return loss is above -10dB and VSWR is greater than 2 at notching frequencies. From current distribution it is observed that current does not reach at antenna at notching frequencies.

There is a slight difference between the simulated and the measured results. The bands are shifted slightly and some ripples are also observed in the measured result. This is entirely due to some tolerances in the fabrication process and also due to the losses at the connector junction in the fabrication design.

**CONCLUSION AND FUTURE SCOPE**

---

**6.1 Conclusion**

The main purpose of this thesis is to obtain rejection bands in UWB antenna. First of all, different types of resonators are discussed which can be used to obtain notch in UWB antenna. A UWB antenna with stepped impedance resonator and circular split ring resonator is designed and simulated. This structure is used to reject triple bands in UWB. Another structure is also designed and simulated having stepped impedance resonator, square split ring resonator and complementary split ring resonator on UWB antenna to notch quadruple bands. At the end, another UWB antenna is designed with stub loaded stepped impedance resonators to reject interfering bands. This design also improves the VSWR as stub is used for impedance matching. The current distribution also demonstrated the working of each stub loaded SIR in rejecting the band. It has been observed that at the notching frequencies the current is not able to reach at the antenna surface and entire current is concentrated on the stub loaded SIRs. The notching bands are 2.4GHz, 3.5GHz, 5.8GHz and 7.5GHz. This structure is fabricated and tested using VNA. The measured results are almost similar to that of simulated results. The reason of slight variation in the results is also explained.

**6.2 Future Scope**

- Other types of resonators can be used to reject different interfering bands and improvement in bandwidth and return loss.
- Various UWB antennas can also be used with different frequency bands to obtain rejection at other frequencies.
- The other feeding techniques like coaxial feeding, aperture coupling and CPW can also be used in future to design the same UWB circular monopole antennas.

## REFERENCES

---

- [1] Yusnita Rahayu, Tharek Abd. Rahman, Razali Ngah, and P.S. Hall, "Ultra wideband technology and its applications," *IEEE Conference on Wireless and Optical Communications Networks*, pp. 1-5, May 2008.
- [2] Yan Zhang, Wei Hong, Zhen-Qi Kuai, and Jian-Yi Zhou, "A compact multiple bands notched uwb antenna by loading SIR and SRR on the feed line," *International Conference on Microwave and Millimeter Wave Technology*, vol. 1, pp. 198-201, 21-24 April 2008.
- [3] Liang Chen, Xiaoyan Zhang, and B. Wu, "Compact UWB bandpass filter with dual notched bands using cascaded shorted-stub loaded SIRS," *IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communication*, pp. 198-201, 29-31 October 2013.
- [4] Jianxin Liang, C.C. Chiau, Xiaodong Chen, and C.G. Parini, "Study of a printed circular disc monopole antenna for UWB systems," *IEEE Transactions on Antenna and Propagation*, vol. 53, no. 11, pp. 3500-3504, November 2005.
- [5] Isha Jindal, and Rajesh Khanna, "Rejection of multiple interfering bands using stepped impedance resonators along the feed," *International Journal of Advanced Research in Computer and Communication Engineering*, vol. 2, no. 5, May 2013.
- [6] N.I. Jo, C.Y. Kim, D.O. Kim, and H.A. Jang, "Design of the ultra wideband antenna with a quadruple band rejection characteristics using a combination of the complementary split ring resonators," *Progress In Electromagnetic Research*, vol. 112, pp. 93-107, January 2011.
- [7] Debdeep Sarkar, Saptarshi Ghosh, Somak Bhattacharyya, and Vaibhav Kumar Sriavstava, "Design of a dual band-notched ultra-wideband antenna using CSRR and modified mushroom-type EBG structure," *Antenna Test and Measurement Society*, vol. 52, no. 2, pp. 466-471, 12-13 February 2013.
- [8] Morikazu Sagawa, Mitsuo Makimoto, and Sadahiko Yamashita, "Geometrical structures and fundamental characteristics of microwave stepped-impedance resonators," *IEEE Transactions on Microwave Theory and Techniques*, vol. 45, no. 7, pp. 1078-1085, July 1997.
- [9] Yuan Yao, Bin Huang, and Zhenghe Feng, "A novel ultra-wideband microstrip line fed wide-slot antenna having frequency band-notch function," *International*

- Conference on Microwave and Millimeter Wave Technology*, pp. 1-4, 18-21 April 2007.
- [10] Filiberto Bilotti, Alessandro Toscano, and Lucio Vegni, "Design of spiral and multiple split ring resonators for the realization of miniaturized metamaterial samples," *IEEE transaction on Antenna and Propagation*, vol. 55, no. 8, pp. 2258-2267, August 2007.
- [11] M. Nosarati, and M. Daneshmand, "Compact microstrip ultra-wideband double/single notch band band-pass filter based on wave's cancellation theory," *IET Microwave Antennas Propagation*, vol. 6, no. 8, pp. 862-868, 7 June 2012.
- [12] D. R. Smith, Willie J. Padilla, D. C. Vier, S. C. Nemat Nasser, and S. Schultz, "Composite medium with simultaneously negative permeability and permittivity," *Physical Review Letters*, vol. 84, no. 18, pp. 4184-4187, 1 May 2000.
- [13] M.R.Vidyalakshmi, and Dr.S.Raghavan, "Comparison of optimization techniques for square split ring resonator," *International Journal of microwave and optical technology*, vol.5, no. 5, pp.280-286, September 2010.
- [14] N.I. Jo, C.Y. Kim, D.O. Kim, and H.A. Jang, "Compact ultra-wideband antenna with quadruple band rejection characteristics using SRR/CSRR structure," *Journal of Electromagnetic Waves and Applications*, vol. 26, no. 5-6, pp. 583-592, 25 July 2012.
- [15] D. Bhardwaj, D. Bhatnagar, S. Sancheti and B. Soni, "Design of square patch antenna with a notch on FR4 substrate," *IET Microwave Antenna Propagation*, vol. 2, no. 8, pp. 880-885, 12 December 2008.
- [16] Su Sander Thwin, "Compact band-notched uwb printed planar inverted cone antennas," *International Journal of Computer Theory and Engineering*, vol. 3, no. 6, pp. 723-726, December 2011.
- [17] Ming-Chun Tang, Shaoqiu Xiao, Tianwei Deng, Duo Wang, Jian Guan, Bingzhong Wang, and Guang-Ding Ge, "Compact UWB antenna with multiple band-notches for WiMAX and WLAN," *IEEE Transaction on Antenna and Propagation*, vol. 59, no. 4, pp. 1372-1376, April 2011.
- [18] Chun Yan Song, Ting Yi Yang, Wei Wei Lin, and Xiao Lin Yang, "Design of a band notched UWB antenna based on EBG structure," *IEEE International Conference on Applied Superconductivity and Electromagnetic Devices*, pp. 274-277, 25-27 October 2013.

- [19] Parisa Lotfi, Mohammadnaghi Azarmanesh, and Saber Soltani, "Rotatable dual band notched uwb/triple-band wlan reconfigurable antenna," *IEEE Antenna And Wireless Propagation Letters*, vol. 12, pp. 104-107, 25 January 2013.
- [20] S. Raghavan, A. Subbarao, and M. Ramaraj, "Novel microstrip-fed UWB antenna with CSRR Slot for Signal Rejection in 5-6GHz Band," *Progress In Electromagnetics Research Symposium Proceedings*, pp. 636-639, 19-23 August 2012.
- [21] Debdeep Sarkar, Kushmanda Saurav, and Vaibhav Kumar Srivastava, "Design of a novel dual-band microstrip patch antenna for WLAN/WiMAX applications using complementary split ring resonators and partially defected ground structure," *Progress In Electromagnetics Research Symposium Proceedings*, pp. 821-825, 25-28 March 2013.
- [22] D. O. Kim, and C. Y. Kim, "Planar UWB antenna with WLAN/WiMAX dual band-notched characteristics using the hilbert- curve slots," *Progress In Electromagnetics Research Symposium Proceedings*, pp. 1494-1497, 27-30 March 2012.
- [23] Chaabane Abdelhalim, and Djahli Farid, "A compact planar uwb antennas with triple controllable band-notched characteristics," *International Journal of Antenna and Propagation*, vol. 2014, pp. 1-10, 12 June 2014.
- [24] V.G. Veselago, "The electrodynamics of substances with simultaneously negative values of  $\epsilon$  and  $\mu$ ," *Soviet Physics Uspekhi*, vol. 10, no. 4, pp. 509-514, January-February 1968.
- [25] Chao-Huang Wu, Shih-Fong Chao, Zou-Ming Tsai, Huie Wang, and Chun Hsiung Chen, "Electronically switchable bandpass filters using loaded stepped impedance resonator," *IEEE Transactions On Microwave Theory and Techniques*, vol. 54, no. 12, pp. 4193-4201, December 2006.
- [26] Mehdi Nosrati and Milad Mirzaee, "Dual-band microstrip bandpass filter using quasi-spiral loaded multiple mode resonator," *IEEE Microwave and Wireless Component Letters*, vol. 20, no. 11, pp. 607-609, November 2010.
- [27] J. B. Pendry, A. J. Holden, D. J. Robbins, and W. J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena," *IEEE Transaction Microwave Theory Technology*, vol. 47, no. 14, pp. 2075-2084, November 1999.
- [28] Christian Enkrich, M. Wegener, F. Pérez-Willard, S. Linden, J. Zhou, T. Koschny, and C. M. Soukoulis, "Optimizing the design parameters for split-ring resonators at

- telecommunication wavelengths,” *Conference on Quantum Electronics and Laser Science*, vol. 3, pp. 1535-1536, 27 May 2005.
- [29] Stefan Linden, Christian Enkrich, Gunnar Dolling, Matthias W. Klein, Jiangfeng Zhou, Thomas Koschny, Costas M. Soukoulis, Sven Burger, Frank Schmidt, and Martin Wegener, "Photonic metamaterials: magnetism at optical frequencies," *IEEE Journal of Selected Topics in Quantum Electronics*, vol.12, no.6, pp. 1097-1105, November-december 2006.
- [30] N. Katsarakis, T. Koschny, M. Kafesaki, E. N. Economou, and C. M. Soukoulis, "Electric coupling to the magnetic resonance of split ring resonators," *Applied Physics Letters*, vol. 84, no. 15, pp. 2943, 12 April 2004.
- [31] Juan Domingo Baena, Jordi Bonache, Ferran Martín, Ricardo Marqués Sillero, Francisco Falcone, Txema Lopetegui, Miguel A. G. Lasí, Joan García–García, Ignacio Gil, Maria Flores Portillo, and Mario Sorolla, “Equivalent circuit models for split ring resonators and complementary split ring resonators coupled to planar transmission lines,” *IEEE Transactions On Microwave Theory And Techniques*, vol. 53, no. 4, pp. 1451-1461, April 2005.
- [32] D. M. Pozar, *Microwave Engineering 3rd edition*, J. Wiley & Sons, New York, 2005.
- [33] Wei Wu, Evgenia Kim, Ekaterina Ponizovskaya, Yongmin Liu, Zhaoning Yu, Nicholas Fang, Y. Ron Shen, Alexander M. Bratkovsky, William Tong, Cheng Sun, Xiang Zhang, Shih-Yuan Wang and R. Stanley Williams, "Optical metamaterials at near and mid IR fabricated by nanoimprint lithography," *Applied Physics A Material Science and Processing*, vol. 87, no. 2 pp.143–150, May 2007.
- [34] M. Makimoto, and S. Yamashita, *Microwave Resonators and Filters for Wireless Communication Theory, Design and Application*, Springer, Berlin, 2001.

## LIST OF PUBLICATIONS

---

### **Proceeding**

Jyotsna Kapoor, and Rajesh Khanna, “Notching of multiple interfering bands using different types of resonators,” *IEEE AP-MTT joint Chapter of Kolkata India Antenna Week*, 26-30 May 2014.

### **Published**

Jyotsna Kapoor, and Rajesh Khanna, “Rejection of Undesired Frequency Bands in UWB,” *International Journal of Advanced Research in Computer and Communication Engineering*, vol. 3, no. 5, pp. 6804-6808, May 2014.