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# Design and Analysis of Microstrip Filtennas

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# Design and Analysis of Microstrip Filtennas

*Thesis submitted in partial fulfillment*

*of the requirements of the degree of*

***Master of Technology***

*in*

***Electronics and Communication Engineering***

**(*Specialization*: *Communication and Networks*)**

*by*


***Karan Kumar Soni***

(Roll Number: 214EC5183)


*based on research carried out*

*under the supervision of*

***Prof. S.K. Behera***

May, 2016


Department of Electronics and Communication Engineering

**National Institute of Technology Rourkela**

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**Prof. S.K. Behera**
Professor

May 27, 2016

## Supervisor's Certificate

This is to certify that the work presented in the dissertation entitled *Design and Analysis of Microstrip Filtennas* submitted by *Karan Kumar Soni*, Roll Number 214EC5183, is a record of original research carried out by him under my supervision and guidance in partial fulfillment of the requirements of the degree of *Master of Technology* in *Electronics and Communication Engineering*. Neither this thesis nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

S.K. Behera

***Dedicated to my family and teachers…***

# Declaration of Originality

I, *Karan Kumar Soni*, Roll Number *214EC5183* hereby declare that this dissertation entitled *Design and Analysis of Microstrip Filtennas* presents my original work carried out as a postgraduate student of NIT Rourkela and, to the best of my knowledge, contains no material previously published or written by another person, nor any material presented by me for the award of any degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the sections "Bibliography". I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

May 27, 2016 *Karan Kumar Soni*

NIT Rourkela

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May 27, 2016 *Karan Kumar Soni*

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# Abstract

The Goal of this thesis is to design and analyses the filtenna, also called by name filtering antenna. Designed by integration of the filter and antenna. In modern day wireless devices multiple antennas are required to make sure that it can be used for multiple communication services, this not only make the system bulky but the power loss is also more. In filtenna using active components can replace them making a system with low profile, more light weight, and energy efficient characteristics. In this thesis includes the first part which is an introduction to computational electromagnetics and using this analysis of microstrip antenna and second is the proposed design of two microstrip filtennas. Under computation electromagnetics, the Maxwell equation and antenna parameter are analyzed using finite difference method. The design and simulation of this filtenna have been done in ANSYS-HFSS-15 simulation tool. The first filtenna designed structure is the integration of the band-rejection filter with monopole antenna for UWB and X-Band applications. Where after applying the open stub it only passes the X-Band i.e. 8-12 GHz. The second proposed filtenna is for overlay cognitive radio application. This is design using the bandpass filter which is integrated with the antenna. In bandpass filter, the frequency tuning is done by varactor diode. This filtenna resonates at frequency 2.6 to 3 GHz and gain of 2.7dB. The fabrication of second filtenna using bandpass characteristics is done and analyzed the results.

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# Chapter 1

# Introduction

## 1.1 Introduction

Nowadays, wireless technology is a crucial part of every human being. Without these we cannot imagine the growth of the technology. As we are growing in the field of wireless communications, there is huge demand for designing and innovations of the "smart" antenna to tune their operating characteristics according to the implementation of wireless technologies. Moreover, use of multiple functional antennas with the controllable functionality like the tuning of the frequency, radiation patterns, polarization, can satisfy the demand for low profile antennas for divergent applications.

A microstrip antennas gives highly required interest of low profile, light weight, furthermore can be effortlessly incorporated with ICs and switching components. It can be produced in printed circuit innovation and in this manner incorporated in mobile phones and different remote applications like satellite communication, rocket, radars and computer networks for large scale generation [1],[2].

Antennas with Reconfigurablilty have broadly concentrated over past two decades. This kind of antenna needs switching/tuning components like P-I-N diodes, RF-MEMS, or varactors to change the electrical properties that affects the radiation characteristics of the antenna which is tunable[3],[4].

At present, the demands of front-end solution of the RF, which is used to minimize the number of antennas in a specific system is increasing [5]. More consideration is paid to multifunction devices (integrated modules for filtering and radiation characteristics, particularly). These multifunction devices involving filtering and radiation characteristics are called filtennas (filtering antennas).

In a communication system with the effectively sensitive receiver, a band-pass filter has to be fundamentally placed in between the antenna and the primary stage of the receiver since the band-pass filter can isolate the required signal at the operating frequency from out band signals. So as to make the configuration minimized, an antenna and a band-pass filter can be integrated into a single module completing both the spatial pre-filtering and the spectral one. Consequently, we require an appropriately designed filtenna again.

Demands on filtennas are not restricted to spatial and spectral filtering only. Antennas are also required to exhibit a prescribed side-lobe level, impedance matching, and polarization characteristics [6].

In the dissertation thesis, we introduce an outline of existing ideas of filtennas.

## 1.2 State-of-the-Arts

Most filtennas are based on an integration of a frequency filter into the antenna structure. Many papers describe an integration of a bandstop and bandpass filter into the feed of an antenna. Some of them deal with horn antennas with filtering nature while some deal with the design of monopole antenna which can give both the spectral filtering and the spatial one at the same time. In the next sub-chapters, existing methodologies are briefly discussed.

### 1.2.1 Filtering Horn Antennas

Horn antennas can provide filtering behaviors, however, small changes has been made in the structure of the antenna. In order to create a filter in a horn, capacitive and inductive elements have to be created using discontinuities and metal obstacles. The obstacles can creates higher modes and specific modes of resonance. In the case of H-plane horn antennas, the filtering action can be added by an incorporated band-pass filter. If discontinuities and metal obstacles cannot be used to create a filter, the role of a frequency filter can be played by a frequency selective surface (FSS) in the aperture of the horn antenna. A decent radiation and filtering performance of a horn antenna can be also achieved by a proper design of a corrugated horn antenna. Such an antenna can reduce noise excited by feeds of a regular horn antenna [6],[7].

### 1.2.2 Antennas with integrated filters

A H-space patch microstrip filtenna have been approached, which having either full ground or defected ground slots behaves as built-in filter type (low pass, high pass, and so forth). These filtenna structures radiate at multi-frequencies of various narrowband and/or broadband which cover the 3G/4G band [8].

Some papers have been discussed on antennas with high band-edge gain selectivity. This structure is the integration of antenna and a band-pass filter on the same substrate. Here, the antenna performs not only functions of a radiation but also act as the resonator of the band-pass filter.

A direct integration of the antennas feeding structure with band-pass filter is the most effortless approach to design an filtennas. We can even design a reconfigurable filtenna by utilizing a reconfigurable band-pass filter.[6]

A slightly different approach of creating an antenna with filtering performance is fulfilling frequency tunable bandpass filter. This is accomplished by varying the properties of the electrical components via integration of varactor diode, pin diode etc within its structure. This blend permits the tuning of the antenna in operational frequency without integrating of active elements and/or biasing lines [2].

### 1.2.3 Filtennas without filter

These Filtennas having antennas and filters are separated and designed in different substrates. The filtering characteristics are accomplished by an appropriate setting of the antenna elements exclusively.

The filtenna structure without filter having many switching elements. The enactment/deactivation of the switching components needs the biasing. Consequently, the conflict of these affects the Electromagnetic characteristics of the antenna. These obstructions show first as undesirable resonance in operating band and second as a adjustment in antenna radiation mechanism from the structure specification if the biasing line is not perfectly composed. Other constraint of this types of structure are the power ought not drive the change to it's non-uniform characteristics in order to prohibit interchannel interference & distortion [2],[6].

## 1.3 Motivation

In modern day wireless devices multiple antennas are required to make sure that it can be used for multiple communication services, this not only make the system bulky but power loss is also more. In filtenna using active components can replace them making system low profile and handheld devices more light weight and energy efficient. Combing the antenna and filters functionally makes the antenna more useful in multimode operation and reduce size and increases flexibility of operation for users.This also introduces pre-filtering of the communication signals so that interference level can be reduced at the receiver end. Recently UWB innovation has picked up as consideration among the educated community and modern wireless universes for the utilization of indoor and handheld framework. Recently cognitive radio system has attracted attention of communication researchers as it can deal with limited bandwidth availability and ever increasing demand of wireless services, to accommodate large number of users and increase data rate, this technology uses dynamic sharing scheme of the bandwidth. Antenna designers on the other hand plays very important role in making this technology work efficiently.

Reconfigurable for cognitive radio application has been proposed here using varactor diodes. A filtenna for x-band application is also proposed using band notch characteristics.

## 1.4 Objective of the Work:

This topic of this thesis is in the area of increasing the functionality of the antenna and making communication system more interference resistant. The Objective of work as following:

- Study of the computational electromagnetics
- Analysis of the electromagnetics equations and microstrip antenna using the finite difference method.

- Filtenna for UWB and X-Band application
- Filtenna for cognitive radio applications

Using ANSYS-HFSS-15 simulation tool.

## 1.5 Organization of Thesis

**Chapter 1:** of the thesis contains the overall introduction to the microstrip filtenna with their advantages and applications and this chapter also contains motivation, objective, literature survey and concludes with outline of this thesis.

**Chapter 2:** This chapter first deals with basic parameters and characteristics of antenna under this focus on microstrip antenna with its feeding mechanism and structure analysis. In second part of this deals with the filter and its types, characteristics and designing of the filter.

**Chapter 3:** This chapter deals with computation electromagnetics in detail. In this Types of computation electromagnetics its need, types, and finite difference method is discussed. The microstrip line problem using FDM is solved and analysed.

**Chapter 4**: This chapter deals with the theory of UWB and cognitive radio system in detail. Here two design proposed first for UWB & X-band application and another for cognitive radio application.

**Chapter 5**: This chapter includes the conclusion and future word regarding the proposed design of the filtennas.

# Chapter 2

# Introduction to Antenna and Filter

## 2.1 Introduction to Antenna

The antenna is specified as “usually a metallic device for receiving and radiating radio waves”.

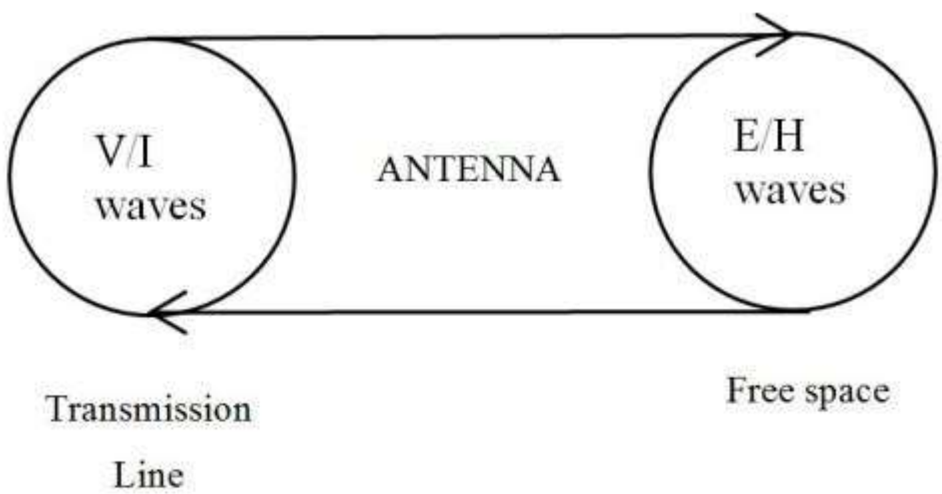



Figure 2.1: Antenna as a Transducer

The process of changing over Voltages/currents waves into E/H is called as Radiation and E/H waves into Voltages/currents waves is called as Induction. The transitional structure that characterized as an interface between free-space and transmission line that converts Current and Voltage waves to Electromagnetic waves and the other way around is called antennas, which is made up with conducting materials. Theoretically, any structure can transmit EM waves, however not all structures can serve as a capable radiation mechanism [9].

An antenna may likewise be seen as a transducer utilized as a part of coordinating the transmission line or waveguide (utilized as a part of controlling the wave to transmit) to the enclosing medium or vice versa. A antenna might be utilized for either transmitting or getting EM energy [9].

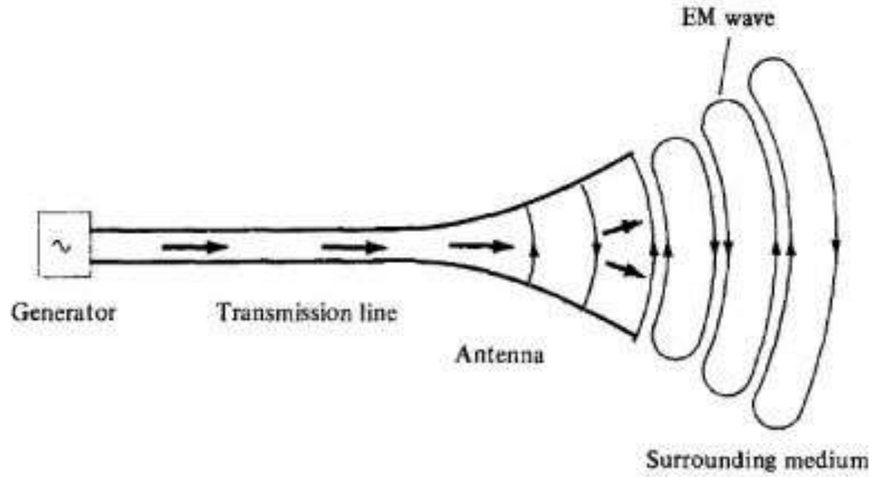



Figure 2.2: Antenna as a matching device between the guiding structure and the surrounding medium

## 2.1.1 Introduction to Microstrip Antenna

The demand of the antenna which having the small size for utilization in mobile devices has increased the need for the microstrip antenna since its invented in 1953 [10],[11]. It is most versatile solution to high performance, spacecraft, aircraft satellite and missile applications, where small size, low profile, light weight, highly effective performance and easily integration with ICs, mass production of the antenna are required. Microstrip antennas categorized in the class of printed antennas, in which radiator that uses printed structure fabricating producers to the feed and radiator structure. This is most prevalent and versatile because of its silent features of good radiation control and minimal effort of fabrication. Microstrip antennas having, more disadvantages as compared to ordinary antennas. It has narrow BW, lower efficiency & gain, radiation leakage and lower power handling limits, highly Q-factor (represents losses) [10].

### 2.1.1.1 Basics of Microstrip Antenna

A most fundamental form of microstrip antenna comprises of a couple of parallel conductors/radiator isolating a dielectric medium, referred as substrate and ground plane below it as shown in Figure 2.3 [11].

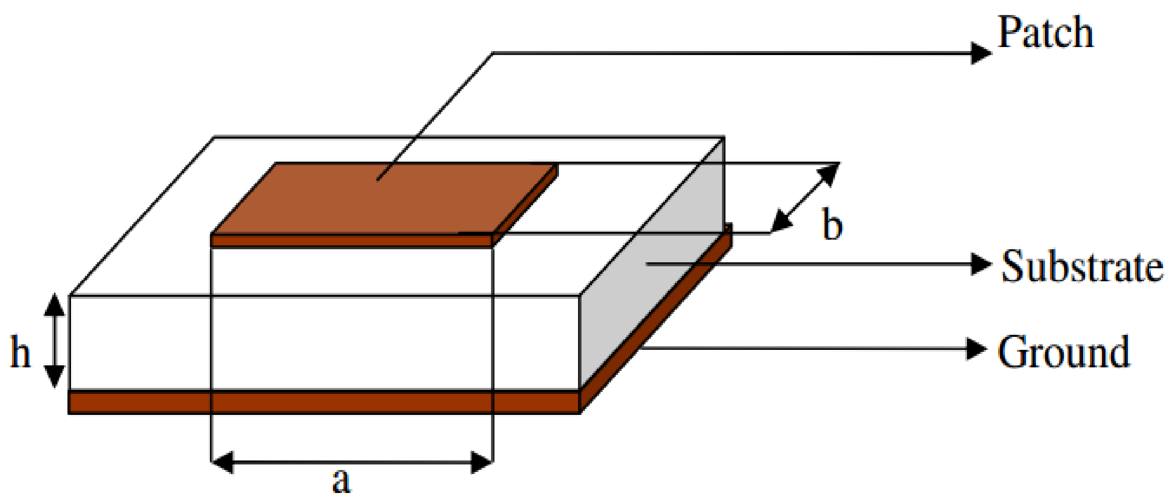



Figure 2.3: Fundamental rectangular microstrip patch antenna structure

In this arrangement, the upper conducting layer called as "patch”, it is the source of electromagnetic radiation, it radiates because fringing occurs at the edge of the patch and into the substrate. The lower conductor i.e. ground plane behaves as a perfect reflector by which radiation of electromagnetic fields reflected back to the free space.

Physically, the patch is a small conductor that is an obvious division of a wavelength in extent. The patch is responsible for accomplishing desired bandwidth because of its resonant behavior. A quasi-TEM mode is generated as the radiating electromagnetic fields are both in the substrate and in free space. In the above Figure ‘a’ shows length and ‘b’ shows width of the patch and substrate height is given by ‘h’. The fundamental resonant mode is TM10 when ‘a’ is greater than b and TM01 is the secondary. If dimension of ‘a’ is less than b than it is vise versa [11].

The transmission line model is the least complex model to portray working of the microstrip antenna [10]. It is sufficiently exact in figuring the input impedances for basic geometries however it is hard to get impedance bandwidth and radiation mechanism, particularly when the substrate is very thin. The cavity model is complex as contrasted with transmission line structure. In this design patch and the ground is expected as electrical plates and edges of the dielectric substrate is surrounded by magnetic walls. The substrate which is used for designing microstrip antenna generally has dielectric constant in the range of 2.2 to 12. Better efficiency and larger bandwidth is provided by the thick substrate and having dielectric constant of low values [11].

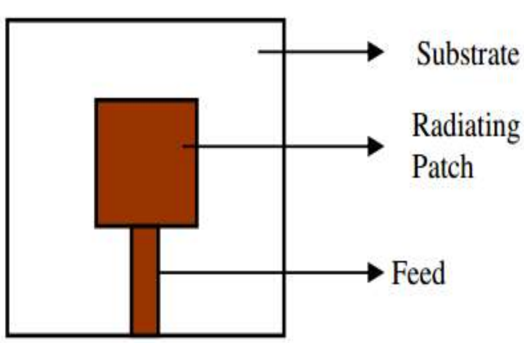
### 2.1.1.2 Feeding Mechanisms

Diverse sorts of feeding methods can be utilized to energize feed of the microstrip patch antenna. Feeding Mechanisms can be categorized in two basic part i.e. contacting and non-contacting/coupled.

- **Directly Contacting to patch:**

  In the contacting feedings, the patch has a direct contact with feedline. The common example of this kind of feeding is microstrip line, coaxial probe in which electrical source is directly connected to radiating patch. In microstrip line feed the conducting strip is directly connected to patch of the antenna [11]. To provide the proper impedance match between the feed line and the patch, for example, inset feed of the direct contacting to patch shown in the Figure 2.4. But as the thickness of the substrate increases surface waves affect the BW. The equivalent circuit is shown in Figure 2.5.

  In coaxial–line feeding technique the inner conductor of coaxial cable is connected to the patch while the outer conductor is connected to ground plane [11]. Its primary advantage is easy to fabricate and impedance matching but difficult to model. It is shown in Figure 2.6 and its equivalent circuit is shown in Figure 2.7.



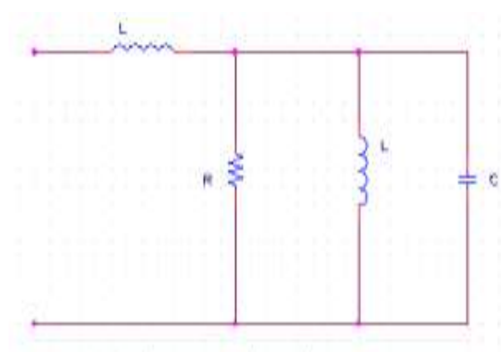



Figure 2.4: Antenna with microstrip feed

Figure 2.5: Equivalent of microstrip feed

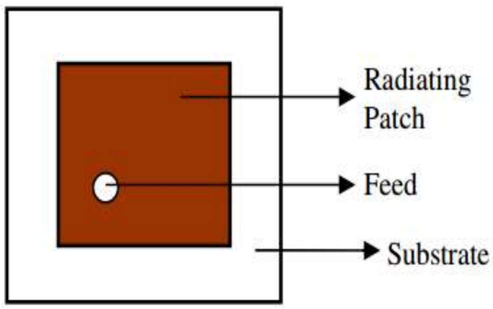



Figure 2.6: coaxial probe feed

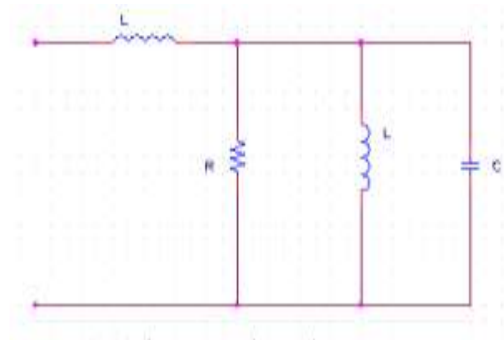


Figure 2.7: Equivalent of coaxial probe feed

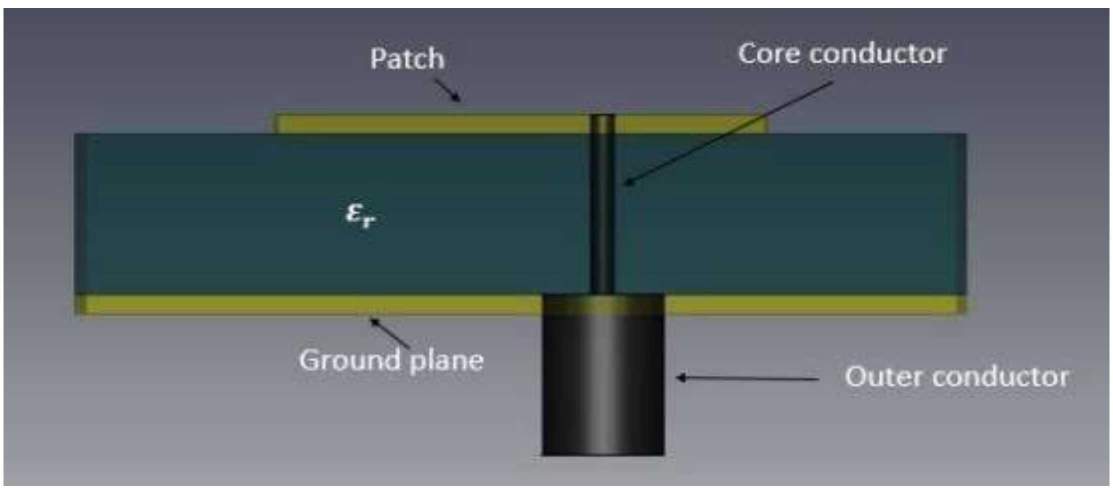



Figure 2.8: Side view of coaxial probe feed

- **Coupled to the patch:**

  In coupling methods of feeding mechanism aperture coupled and proximity coupled are most generally utilized. Coupling of the electromagnetic field is done between the feed and the radiating patch of the antenna.

  In Aperture coupled technique ground plane isolates two substrates of which the below one has the feedline by which coupling of energy is done to the patch through the slot on the ground plane, as shown in the Figure 2.9. Its equivalent is given in Figure 2.10. Aperture coupled gives narrow BW [11].

  And proximity coupled feed also consist of two substrates but feedline is sandwiched between them. The upper substrate having radiator/patch and in bottom one reflector/ground plane, in this, the coupling is of nature of capacitive. As shown in the Figure 2.11 proximity coupled gives largest BW [11]. This feeding technique is most difficult to fabricate and have low spurious radiation mechanism. The equivalent circuit is given in Figure 2.12.

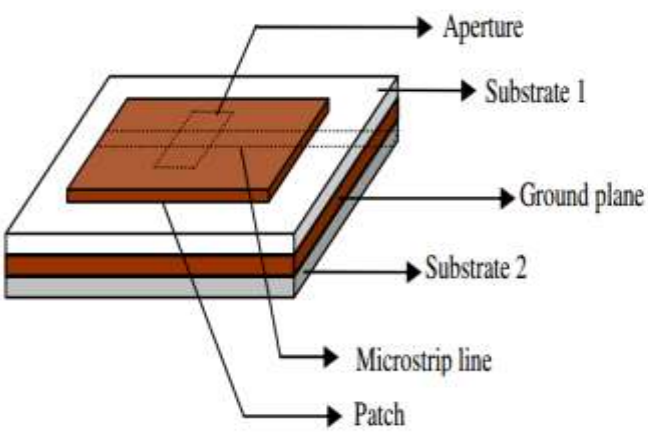



Figure 2.9: Antenna with Aperture Coupled

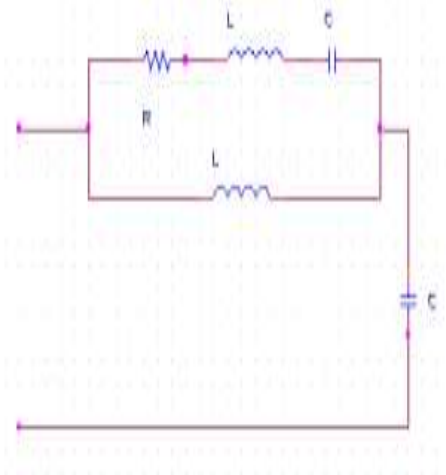


Figure 2.10: Equivalent of Aperture Coupled

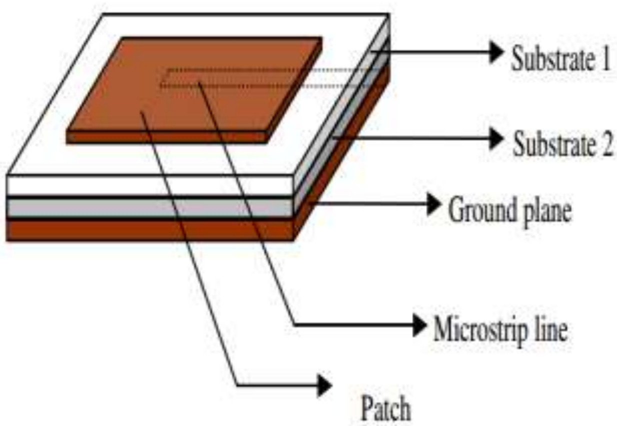



Figure 2.11: Antenna with Proximity Coupled

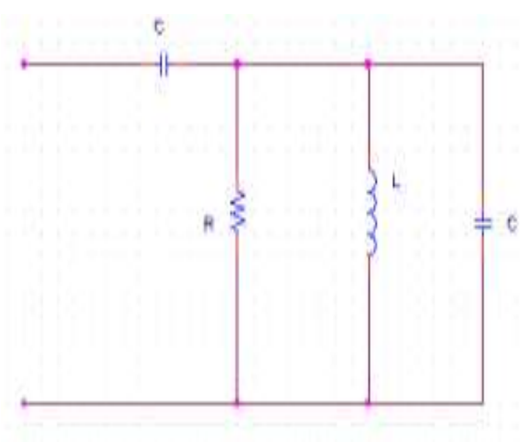


Figure 2.12: Equivalent of Proximity Coupled

### 2.1.1.3 Structural Analysis of Microstrip Antenna

There are various models of microstrip antenna. The simplest of all the models is transmission line structure. It is most effortless however the disadvantage of utilizing it will be it yields less precise results and it needs the flexibility. Essentially the transmission line model represents the microstrip antenna by two slots isolated by a $Z_C$ i.e. low-impedance line of the length L, width W and height H, as shown in Figure2.13 and Figure 2.14 [10].

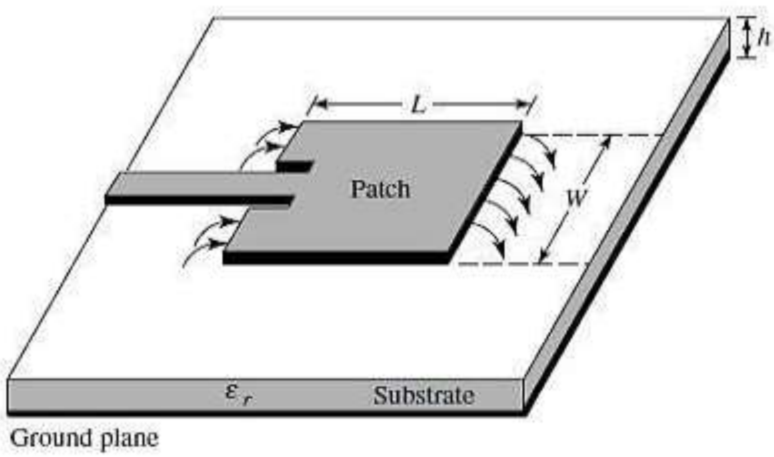



Figure 2.13: Microstrip Patch Antenna

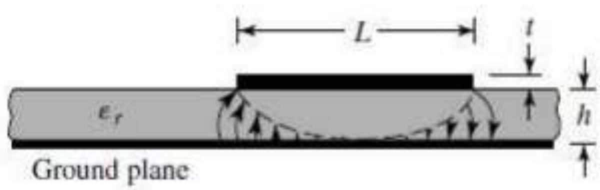



Figure 2.14: Side view of Microstrip Patch Antenna

### Fringing Effects

The field at the edges of the patch undergo fringing as it is truncated, the amount of fringing is the function of the height and the length or breadth of the patch this is shown Figure 2.15. Generally L/h ratio is >> 1, the fringing fields are less but it should be taken into account as it influences resonating frequency of the antenna. The amount of fringing of the antenna is dependent on the dimensions of the patch and the height of the substrate. Because of the fringing electric field lines goes in non-homogeneous material, typically air and substrate, an effective dielectric constant $\varepsilon_{reff}$ is introduced because the fields are not only in substrate but also in air that is to account for fringing and the wave propagation in the line. This is written mathematically by equation 2.1 [10].

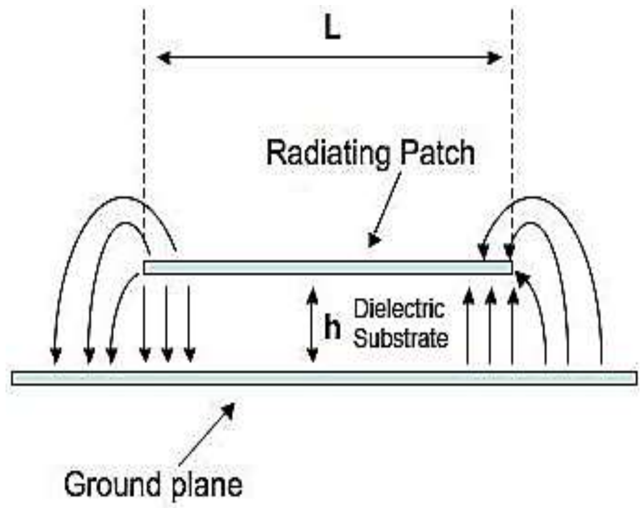



Figure 2.15: Fringing Field Effect

$$W/h >> 1 \tag{2.1}$$

$$\xi_{reff} = \frac{\xi_r + 1}{2} + \frac{\xi_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{2.2}$$

The genuine length of the rectangular patch is more than the physical length. It is because of the fringing field turning out from the radiating slots. The extension of length on each side of the antenna $\Delta L$ is the function of the $\varepsilon_{reff}$ and W/h, as written in below equation

$$\frac{\Delta L}{h} = 0.412\frac{(\xi_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\xi_{reff} - 0.258)(\frac{W}{h} + 0.8)}$$

(2.3)

The genuine physical length of the patch because of the expansion length not equal to new length is considered as

$$L = L_{eff} - 2\Delta L \tag{2.4}$$

The $L_{eff}$ as dominant mode $TM_{010}$ the length of patch is equal to λ/2 is given by

$$L_{eff} = c/f_r$$

$$= \frac{c_0}{2f_r\sqrt{\varepsilon_{reff}}} \tag{2.5}$$

Where $f_r$ is resonating frequency for which antenna is designed and $c_0$ is the speed of light in vacuum.

Width of the patch can be calculated by this formula for the dominant mode $TM_{010}$ as there is no fringing fields along the width so no need to take effective dielectric constant.

$$w = \frac{c_0}{2f_r}\left(\frac{\varepsilon_r+1}{2}\right)^{-1/2} \tag{2.6}$$

The antenna resonates at the frequency given by equation 2.6 for the dominant mode $TM_{010}$

$$f_r = \frac{c_0}{2L\sqrt{\varepsilon_{reff}}} \tag{2.7}$$

The antenna will radiate at the frequency given in equation 2.7 when considering $\varepsilon_{reff}$ and $L_{eff}$

$$f_r = \frac{c_0}{2(L+2\Delta L)\sqrt{\varepsilon_{reff}}} \tag{2.8}$$

### 2.1.3 Antenna Parameters

The performance of an antenna describes by the various parameters like radiation pattern, beam width, radiation power density, radiation intensity, directivity, antenna efficiency & gain, polarization etc [9], [10]. The basic introduction of these parameters defines below:

- ***Radiation Pattern*****:** It is graphical representation of the radiation properties of the antenna w.r.t. coordinates i.e. it is function of directional coordinates. This patterns can be either magnetic/ electric field or power of the antennas that commonly in decibels (dB) [9], [10].

- ***Beamwidth:*** The resolution capabilities of the antenna that distinguish between two adjacent radiating sources / target is described by the parameter beamwidth. We are taking consideration of two basic beamwidth i.e. HPBW (half power beamwidth) and FNBW (first-null beamwidth).

- ***Radiation Power Density****:* The power associated with the electromagnetic wave is described as instantaneous poynting vector of the E and H fields intensity defined as $\mathcal{W} = \mathrm{E}\, X\, \mathcal{H}$.

- ***Radiatio Intensity:*** It is a far field parameter of the antenna which is defines as the power radiated from an antenna per unite sloid angle in particular direction. It is function of the radiation density and distance of the target.

- ***Directivity*****:** It is the ratio of the radiation intensity in particular direction to the averaged over all direction of an antenna. It is a measure of how 'directional' an antenna's radiation pattern.

- ***Antenna Efficiency and Gain****:* The total antenna efficiency $e_0$ is used to take into account losses at the input terminals and within the structure of the antenna. Antenna gain is related to directivity of the antenna. Gain is the function of the radiation intensity and total input power.

- ***Polarization:*** Polarization is defined as the electric field orientation of the antenna. The field must be observed along the direction of propagation. It is classified as linear, circular, or elliptical.

# 2.2 Filters:

There are numerous approaches to outline RF and Microwave filters. The filters are the two-port system used to control the frequency response in the RF or Microwave framework. They permit transmission of the signal frequencies inside their pass-band and attenuate signals outside their pass-band [12],[13]. Essential RF and Microwave filters sorts below:

- ***Transmission line stubs filters:*** It is implemented by replacing the lumped elements from the transmission lines.
- ***Coupled line filters:*** This type of filter can be implemented by using the coupling of the transmission line using the quarter-wave matching transformers.
- ***Inter-digital filters:*** When short-circuited transmission line structure take the structure of the interlaced fingers, Inter-digital filters are formed.
- ***Comb-Line filters:*** It is implemented by using of the capacitive coupled quarter-wave transmission line.
- ***Waveguide discontinuity filters:*** The high power and low loss handling characteristics of the waveguide lend themselves to use of waveguide in specialized filters.
- ***Elliptic function filters:*** At the point when n coupled transmission lines are set between the parallel plates. The system is a 2n port network that is reduced to n port system but leaving all the ground ports open-circuited [13].

## 2.2.1 Microstrip Line Filters:

Basic structure of the microstrip is shown in Figure2.16. A microstrip line thickness t and width W made up of the conductor is placed above dielectric substrate, which having height of h and relative constant of $\varepsilon_r$, and there is one ground plane placed in the bottom of the substrate.

The microstrip having inhomogeneous nature that is the reason it will never have the capacity to back an perfect TEM wave. These fields are particularly immaterial than electric and magnetic segments. In this case, the dominant mode will carry on like a TEM mode, hence, the transmission line for TEM can also be appropriate for microstrip line.

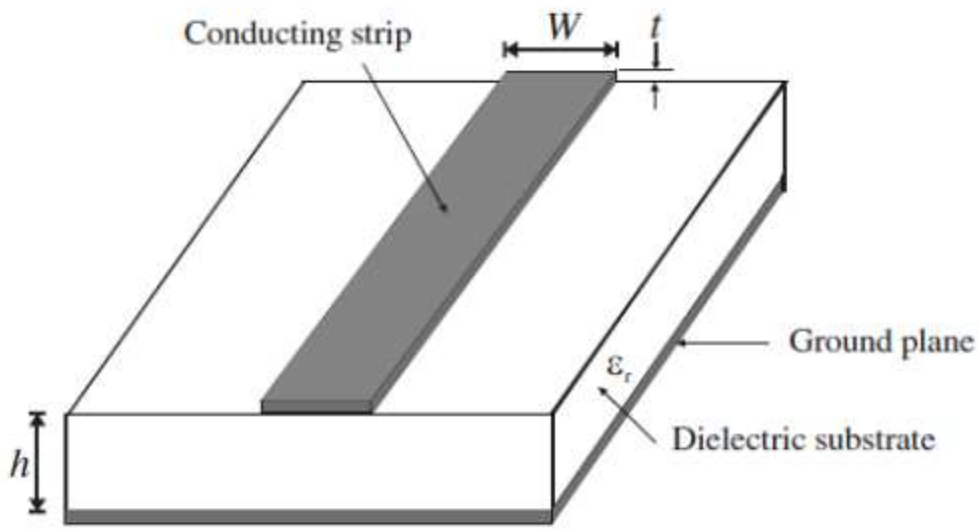
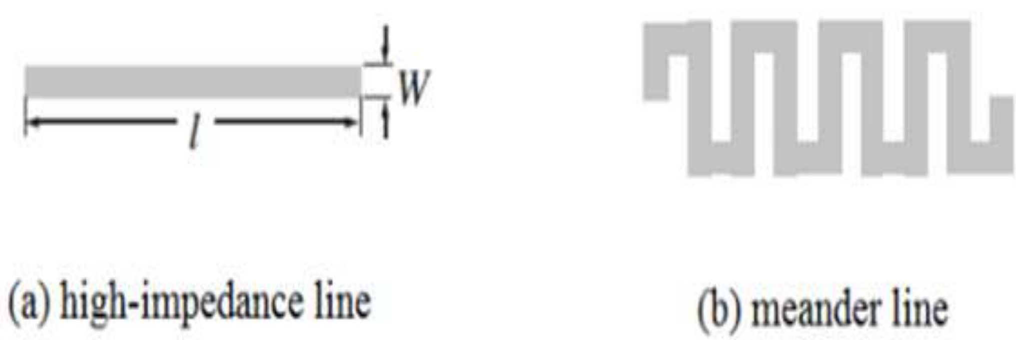



Figure 2.16: Microstrip structure

**2.2.1.1 Microstrip Components:**

To design the filters microstrip components taken in to the accounts. It is basically lumped and quasi lumped components and resonators. The size of these components smaller as compared to wavelength of the free space. These illustrated in Figure 2.17 and Figure 2.18.



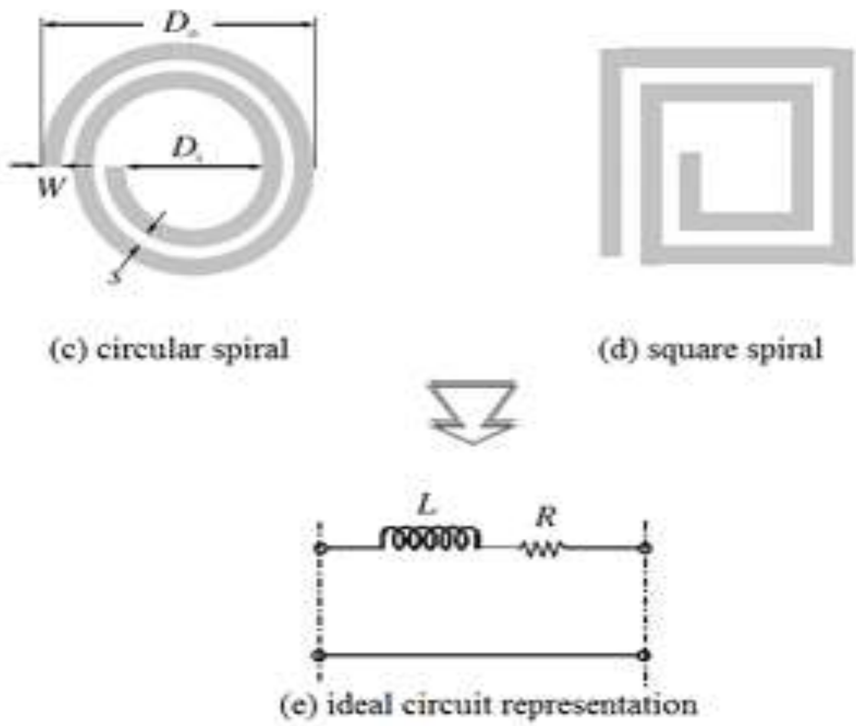



Figure 2.17: Lumped Elements Inductors

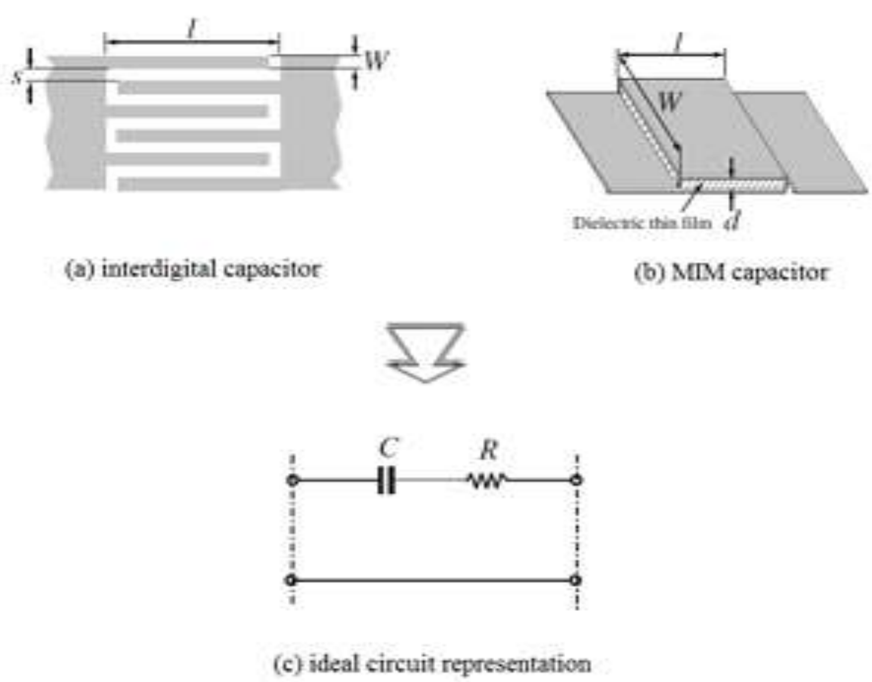



Figure 2.18: Lumped Element Capacitors

**2.2.1.2 Microwave Resonator:** A structure which is capable to enclose at least one oscillating electromagnetic field is called a Microstrip resonator. There are various forms of microstrip resonators as shown in Figure 2.19.

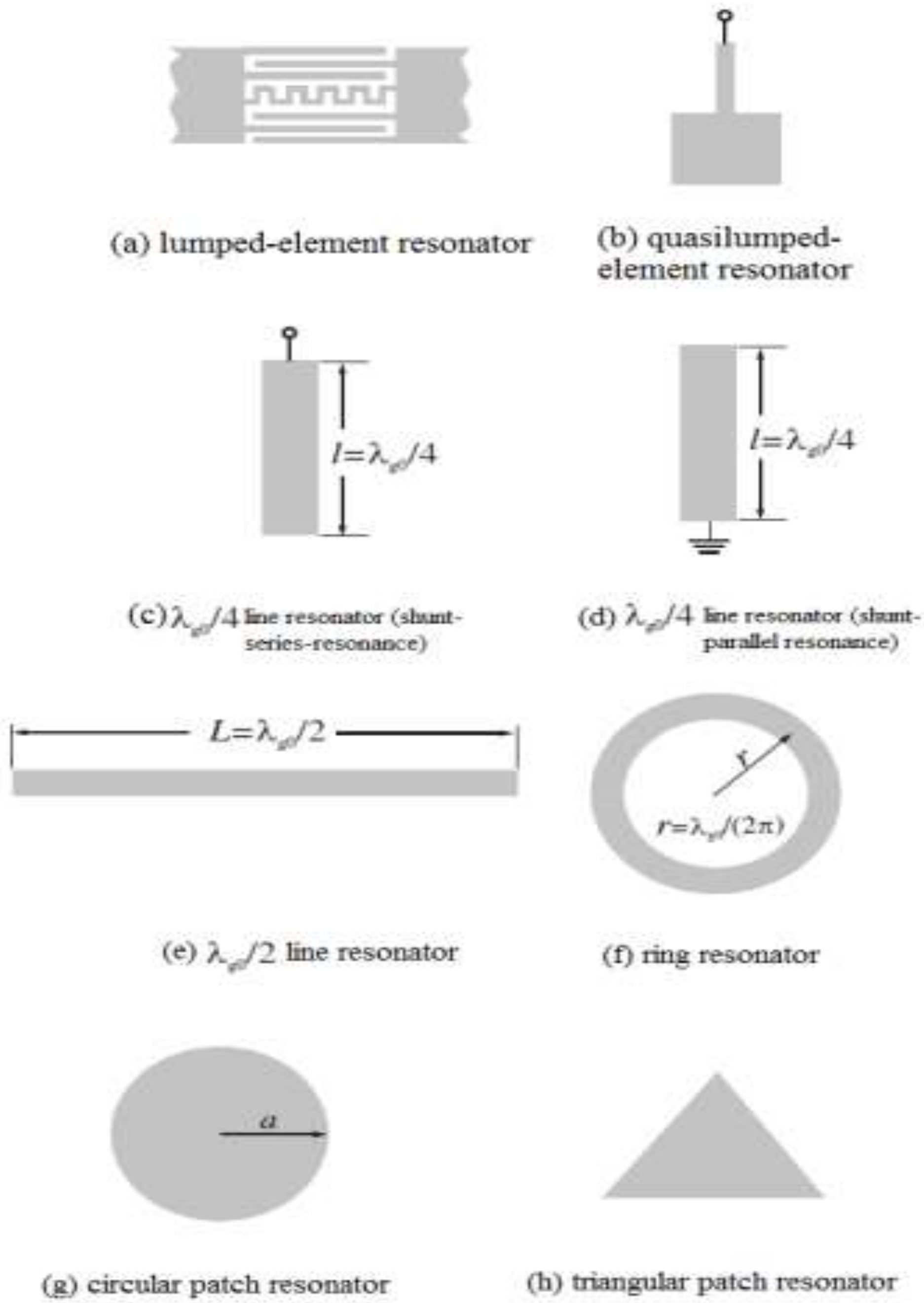



Figure 2.19: Some Microwave Resonators

### 2.2.1.3 Types of the microstrip filters:

The microstrip filters basically classified as Lowpass and Bandpass filters, Highpass and bandstop filters, coupled resonator filters, Ultra-wideband filters, electronically tunable and reconfigurable filters etc.

- ***Lowpass and Bandpass filters:*** Lowpass is designed basically in three types Stepped-impedance L-C ladder type, L-C ladder type using open circuited stub, semi-lumped lowpass filter. Bandpass is design classified as end coupled, parallel-coupled, hairpin-line, and combline filters etc.
- ***Highpass and Bandstop filters:*** Highpass filters designed in two ways quasi lumped and optimum distributed HPF. Bandpass filters implemented by three ways narrow-band, bandstop using open stub, using RF chokes.
- ***Coupled-Resonator Filters:*** It plays a vital role in microwave filter, mainly designing of the narrow-band bandpass filter, which is used in various microwave applications. This design is based on coupling coefficients of intercoupled resonators and the external Q-factor of the I/P and O/P resonators.
- ***Ultra-wideband filters:*** These types if filter designed for the using of the Ultra-wideband frequency range.
- ***Electronically Tunable and Reconfigurable Filters:*** It plays vital role in the future cognitive radio and radar applications because it uses active & passive switching or tuning elements like p-i-n diode, varactor diode, RF-MEMS etc. As we are changing the parameters of these components the function and characteristics of the filter will be changed.

## 2.2.2 Filter Design Methods:

The designing of filters basically done by two methods first is image parameter and another is network synthesis method. The introduction about this methods are given below:

- **Filter Design by the Image Parameter Technique:** The image parameter for the analysis of circuits is a wave perspective commonly utilized for analysis of transmission lines, such circuits include filters. Therefore filters can be composed by the image parameter technique [14], [12].

- **Filter Design by the Network Synthesis Technique:** This technique is depends on the transfer function of the circuit, which gives the transmission coefficient. The input impedance can be obtained from transfer function. The basic filter using this methods are maximally flat response filter, equal ripple response and linear-phase response filter [14],[12].

### 2.2.3 Classification of Frequency Reconfigurable Techniques

Frequency control in an antenna can be achieved by controlling current distribution in the patch and the ground. In literature many types of defected microstrip structure (DMS) [15] and defected ground structure (DGS) [16] has been reported which are used to get desired output of resonating frequencies. In the patch, the current distribution can be changed and thus by use active switches like micro electro mechanical systems (MEMS) and PIN diodes [3],[4] can also change in resonance frequency or even by using a photo-conductive switches. Integration of electronic switches in microstrip patch antennas are very easy by connecting, so researchers are been continuously working in this field to design new multifunctional antennas. Beside ease of fabrication there are numerous issues that limits its usage like non-linearity, interference, losses, negative effect of DC biasing circuit and size by the biasing circuit. Table 2.1 shows advantages and disadvantages of tunable switching components used in reconfigurable antennas.

Table 2.1 comparison of different tunable components

| **Tunable component** | **Advantages** | **Disadvantages** |
|---|---|---|
| RF MEMS | Insertion loss is less, very high linearity, good isolation, low power loss and consumes no DC power used. | High control voltage is needed (50-100 V) poor reliability, switching speed is slow, discrete |

| | | |
|---|---|---|
| | | tuning, limited lifecycle. |
| PIN diodes | Driving voltage needed is less, tuning speed and power handling capabilities is high, very low cost, and very reliable as no rotating part. | In its ON state needs high DC bias voltage and consumes large amount of energy, on linear characteristics, poor quality factor and discrete tuning. |
| Varactor | It gives continuous tuning, and consumes less energy than others. | Highly nonlinear and have low dynamic range and require complex circuitry. |
| Optical switches | More reliable , linear characteristics , no biasing circuits | Lossy behavior, complex activation mechanism |
| Physical technique | Does not require bias circuits which eliminates interference , losses and radiation pattern distortion | Slow response, cost, power requirements, size, complex integration, |
| Smart materials | Size as it has high relative permittivity and permeability | Low efficiency |

## 2.3 Summary:

In these chapter introduction to microstip antenna and filter is discussed. In Microstrip antenna and its feeding mechanism structural analysis, antenna parameters are analyzed. Apart from this there is discussion about different types of filter, their designing methods and the reconfigurablity of the filter.

# Chapter 3

# Analysis of Microstrip Antenna using Finite Difference Method

## 3.1 Computational Electromagnetics

For invention in field of wireless technology and electromagnetic, Maxwell's equation plays vital role. Maxwell's equation is essential for analysis of the EM waves. They are rapidly being used to study of electrical engineering technologies appreciate electrical material, cellphones, automation, lasers and photonic devices, and also further in fields appreciate electromagnetics, to study how electromagnetic fields interact by the whole of and persuade biological processes [9],[17].

For solving the equations like differential and integral there are basically two types of methods, first one is analytical method and another is numerical method. Analytical method gives exact solution for the equation, but not necessarily. It totally depends on the type of the equation. As we are moving toward pure electromagnetic field analysis, there exist the complex equation that cannot be solved by analytical methods, therefore use of numerical methods comes into the picture. Some example of the analytical solutions are separation of variable, series expansion, Laplace & Fourier transforms etc [9],[17].

Numerical methods some times called as non-analytical method. Computational electromagnetic having various types, the most commonly used methods are:

- Finite Difference Method (FDM)
- Method of Moments (MoM)
- Finite Element Method (FEM)
- Boundary Element Method (BEM)
- Transmission-Line-matrix Method (TLM)
- Hybrid Techniques (HT)

The partial differential equation is solved by finite difference method and finite element method. And the method of moments is used to solve integral equation.

# 3.2 Why FDM ?

## 3.2.1 Classification of Computation Electromagnetics

The group of techniques in CEM can be covert in other ways. One feasible classification is shown in Figure 3.1. This categorization divides CEM directed toward two major categories: numerical methods and high-frequency or asymptotic methods. Numerical methods are best gifted for problems to what place the length of the process under experiment is in the decision of the wavelength to an amount tens of wavelengths. These methods require into assets and liability the wave nature of the electromagnetic sensation and are appropriately based on discretization's of differential or integral formulations of Maxwell's equations [9],[17].

Both fundamental and differential equation based numerical methods can be divided in two parts: frequency domain and time domain. On the other hand, valuable frequency methods are used when the term of the objects is multiple wavelengths in quantity and the nature prefer not be easily considered. Geometrical optics, for lesson, relies essentially on the concept of rays to ideal the trade behavior. Since this work's objective is to design antennas whose sizes are in the term of an amount wavelengths, only a numerical method can be recommended, section to which FDTD belongs [17].

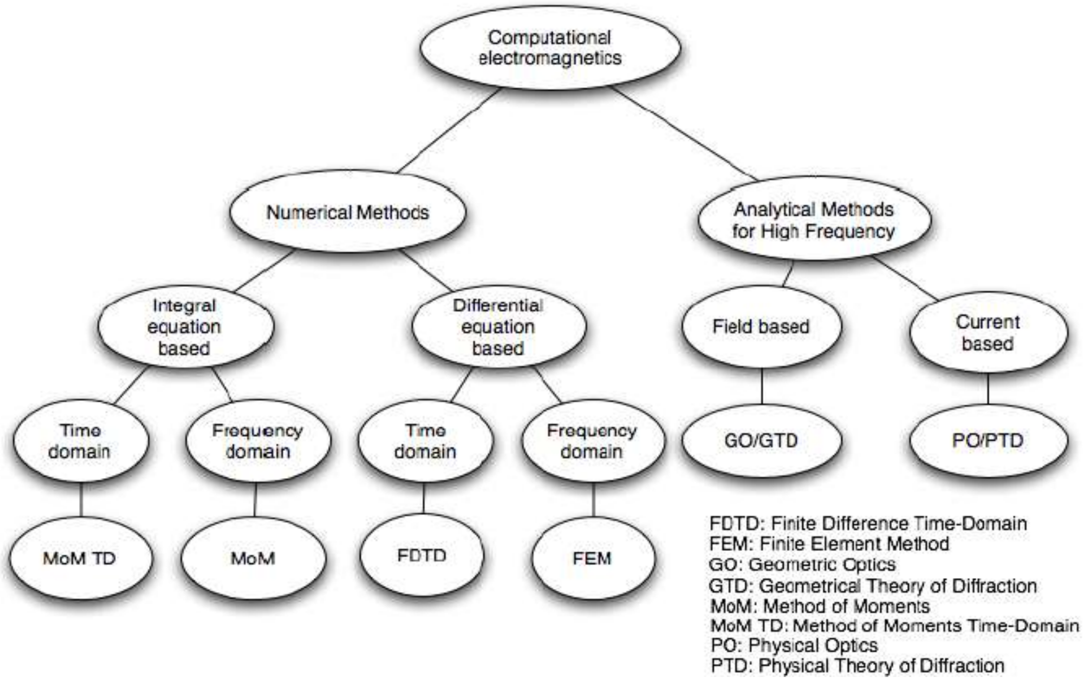



Figure 3.1: Classification of computational electromagnetics

### 3.2.2 FDM Advantages:

For antenna experiment and study in the sub-wavelength domain, there are currently three cleanly established methods: first one is the method of moments (MoM), second one is the finite element method (FEM) and the last one is finite difference time-domain method (FDTD).

MoM is an integrated equation based on numerical method which is used for last decades. It started as, and consistently speaking, still is used frequently as a frequency-domain technique but now a day, there has been some work going on time-domain formulations. This scattering type problems involves very large structures, such as aircrafts and war missiles. It has been used to successfully analyze wire antennas of almost arbitrary configuration, aperture antennas, reflector antennas, etc.

FEM is a differential equation based numerical manner that dates subsidize to the 1940s and originated from the needs for solving complicated elasticity, structural examination problems in social and aeronautical engineering. Similarly to MoM, it is commonly known as a frequency-domain approach, during time-domain formulations also exist. Its review to antenna examination has been largely in scanty problems and micro strip patch antennas.

### 3.2.3 Types of FDM

It is classified in two types:

- ***Finite Difference Time Domain Method (FDTD):*** This method is good for Modeling big, bad and ugly problems, Modeling devices with nonlinear material properties and simulating the transient response of devices [17].

  *Benefits:* Excellent for large-scale simulations & transient analysis, highly versatile, error mechanisms are well understood, accurate, robust etc.

  *Drawbacks:* Tedious to incorporate dispersion, difficult to solve curved surfaces.
- ***Finite Difference Frequency Domain Method (FDFD):*** This method is good for Modeling 2D devices with high volumetric complexity, Visualizing the fields and Fast and easily formulation of new numerical techniques [17].

  *Benefits:* accurate, robust, excellent for field visualization, highly versatile etc.

  *Drawbacks:* does not scale well to 3D, structured grid is inefficient. Slow and memory inefficient.

### 3.2.4 Practical Applications

- Transmission-line problems
- Waveguides
- Microwave circuit
- EM penetration and scattering problems
- EM exploration of minerals and
- EM energy deposition in human bodies

## 3.3 The Finite Difference Method:

It is invented by A.Thom in 1920s by the title of “The Method of Squares” to solve nonlinear hydrodynamic equations. This method is based on approximations which permits replacing differential equation by finite difference equations. It is Powerful Numerical Method to solve PDE. A problem is uniquely defined by three things:

- A partial differential equationsuch as Laplace's or Poisson's equations.
- A solution region.
- Boundary and/or initial conditions

FDM include three steps first is dividing the solution regions into the grid of nodes (the common example of grid are shown in Figure 3.2), second is approximating the given differential equation that rates the dependent variable at a point in the solution region to its value at neighboring points and third is solving the difference equation subjected to the prescribed boundary condition and/or initial conditions [17],[18].

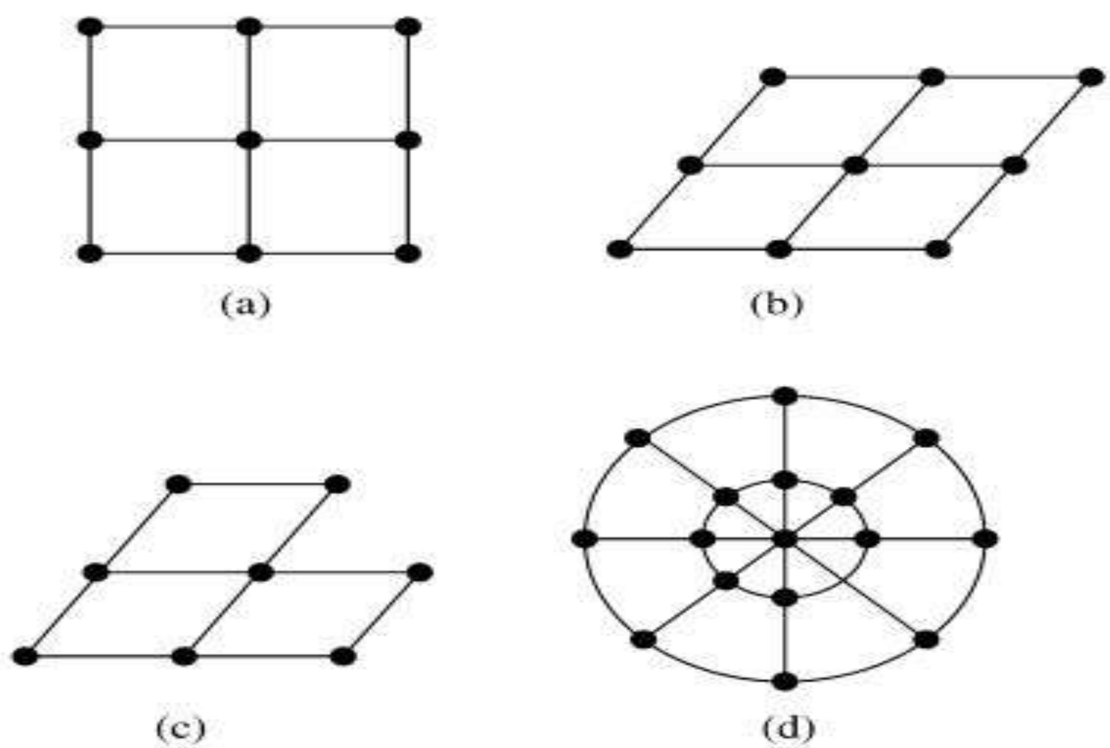



Figure 3.2: Common grid patterns: (a) rectangular grid, (b) skew grid, (c) triangular grid, (d) circular grid

## 3.3.1 Finite Difference Scheme:

For understanding FDM first we take a function $f(x)$ as shown in Figure 3.3. The approximation to its derivative, slope or tangent at $P$, given as:

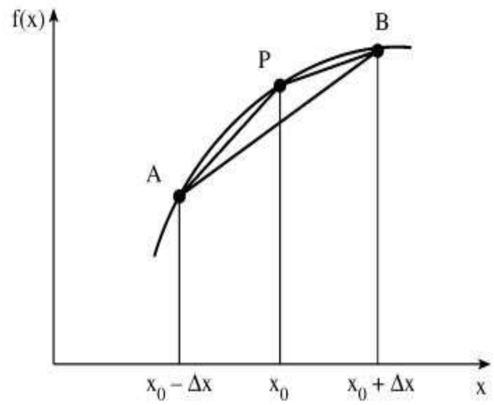



Figure 3.3: Function $f(x)$

PB : Forward Difference Formula

$$f'(x_0) \cong \frac{f(x_0 + \Delta x) - f(x_0)}{\Delta x} \tag{3.1}$$

AP : Backward Difference Formula

$$f'(x_0) \cong \frac{f(x_0) - f(x_0 - \Delta x)}{\Delta x} \tag{3.2}$$

AB : Central Difference Formula

$$f'(x_0) \cong \frac{f(x_0 + \Delta x) - f(x_0 - \Delta x)}{2\Delta x} \tag{3.3}$$

And Second Derivatives of $f(x)$ at P as:

$$f''(x_0) \cong \frac{f(x_0 + \Delta x) - 2f(x_0) + f(x_0 - \Delta x)}{(\Delta x)^2} \tag{3.4}$$

After applying the finite difference scheme the equation is simplified and it can be solve by either iteration method or band matrix method [17].

### 3.3.2 Solution to One Dimension Boundary Problem

To solve 1-D boundary problem we are taking the function which is defines as $-\emptyset'' = x^2$, $0 \leq x \leq 1$ and given the condition is $\emptyset(0) = 0 = \emptyset(1)$ using FDM. For solve it first partition the whole space $0 \leq x \leq 1$ into N equal level with sections of length $h = 1/N$ . so that there are $(N+1)$ nodes. It is solve as

$$-x_0 = \frac{d^2\emptyset}{dx^2} \rightarrow at\ x = x_0 \ \cong \frac{\emptyset(x_0+h) - 2\emptyset(x_0) + \emptyset(x_0-h)}{h^2} \tag{3.5}$$

$$-x_j^2 = \frac{\emptyset_{j+1} - 2\emptyset_j + \emptyset_{j-1}}{h^2} \tag{3.6}$$

Thus

$$\emptyset_j = 0.5 * (\emptyset_{j+1} + \emptyset_{j-1} + x_j^2 h^2) \tag{3.7}$$

Using FD scheme acquire an approximate solution for different estimations of N. The Exact Solution is found to be:

$$\emptyset = x(1 - x^3)/12 \tag{3.8}$$

Hence we plotted the plot between for the different values of N for the given function as shown in below Figure 3.4 and 3.5.

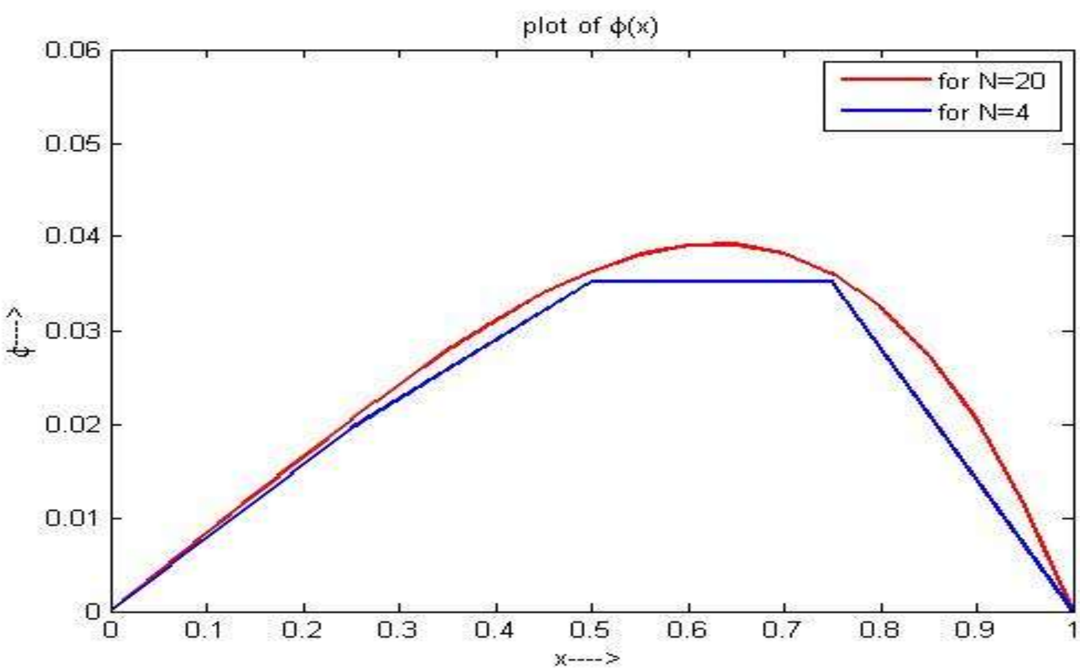


Figure 3.4: Continuous curve for $N = 20$ and $N = 4$

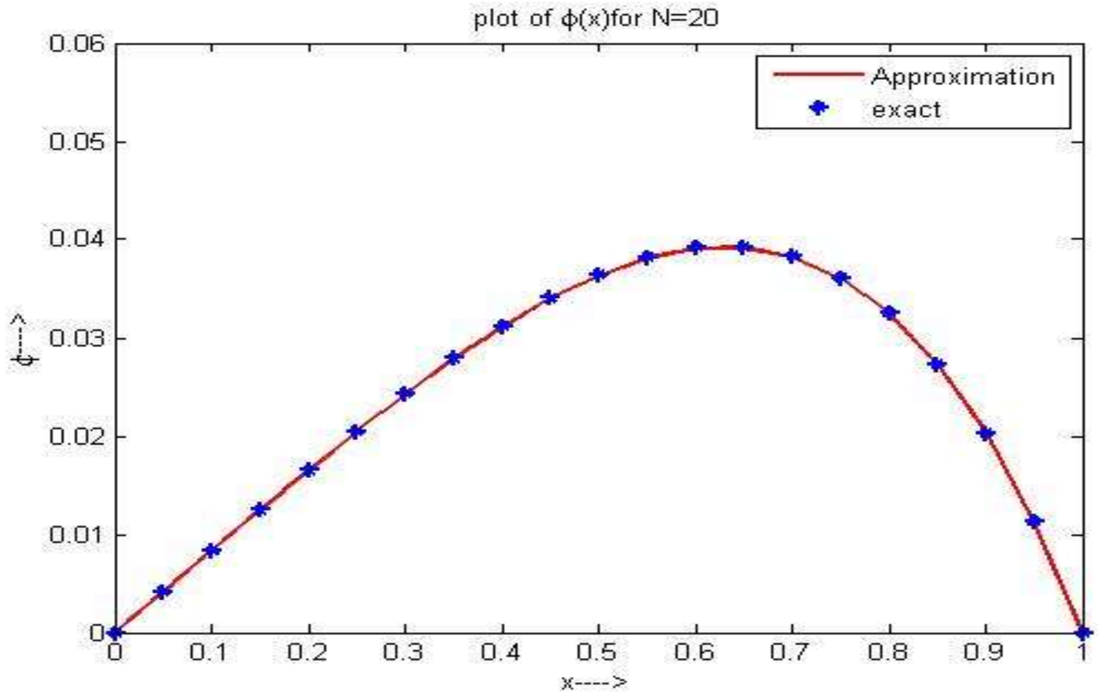


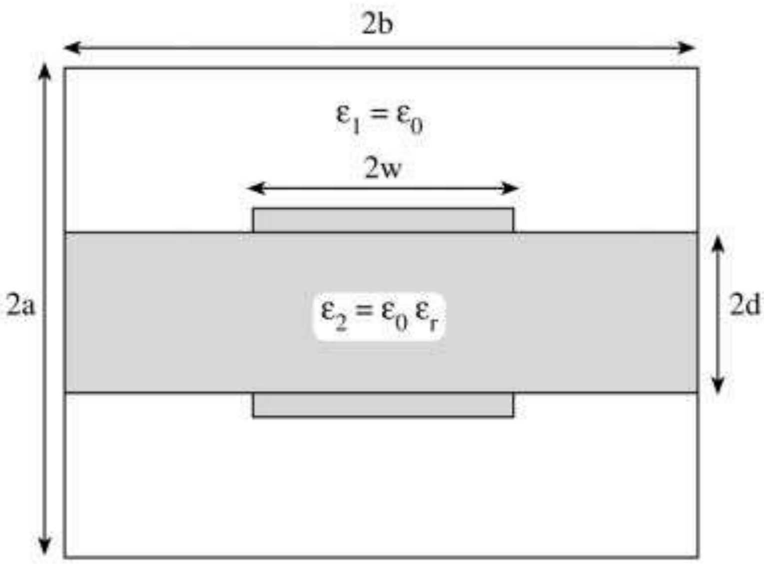

Figure 3.5: Continuous curve for $N = 20$ at approximate solution and exact solution

The above Figure shows as we increase the no of iterations the curve shifted towards the exact solution of the function [17].

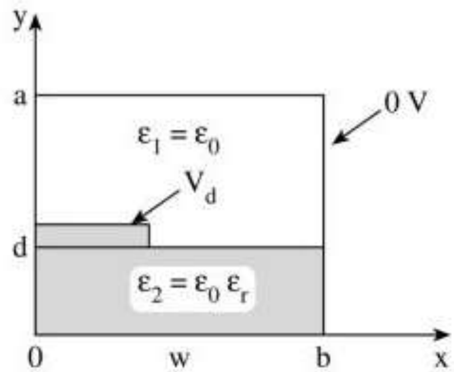
### 3.3.3 Solution to Microstrip Line

The finite difference techniques are suited for analyzing the characteristic impedance, phase velocity, and attenuation of the transmission lines (eg. polygonal lines, shielded strip lines, coupled strip lines, microstrip lines, coaxial lines, and rectangular lines.)

Consider the microstrip line as shown in Figure 3.6. The geometry is deliberately selected to illustrate how one uses the finite difference technique to account for discrete in homogeneities and lines of symmetry [17].




(a)




(b)

Figure 3.6: (a) Shielded double strip line with partial dielectric; (b) simplified by making full use of symmetry

We are taking the TEM mode into account because neither of E nor H fields in the direction of propagation. So, Laplace's equation satisfied the fields. The TEM mode selection gives good approximation if the line dimensions are much smaller than half wavelength, i.e. operating frequency below than cutoff frequency.

The finite difference approximation of Laplace's equation, $\nabla^2 V = 0$, has been derived in Equation

$$V_0 = \frac{1}{4}\{V_1 + V_2 + V_3 + V_4\} \tag{3.9}$$

On the dielectric boundary, the boundary condition,

$$D_{1n} = D_{2n} \tag{3.10}$$

Must be imposed. We recall that this condition is based on Gauss's law for the electric field, i.e.

$$\oint_l D\,dl = \oint_l \in E\,dl = Q_{enc} = 0 \tag{3.11}$$

Since no free charge is deliberately placed on the dielectric boundary. Substituting $\mathbf{E} = -\nabla V$ in Eq3.11.

$$0 = \oint_l \in \nabla V\, dl = \oint_l \in \frac{\partial V}{\partial n}\, dl \tag{3.12}$$

Where $\frac{\partial V}{\partial n}$ denotes the derivative of V normal to the contour L. Applying above equation to the interface as shown in Figure 3.7.

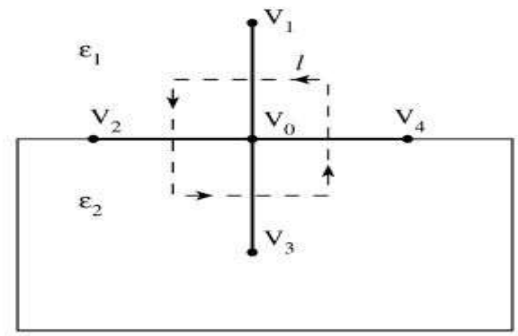



Figure 3.7: Interface b/w dielectric mediums

Thus $$0 = \in_1 \frac{(V_1-V_0)}{h} \times h + \in_1 \frac{(V_2-V_0)}{h} \times \frac{h}{2} + \in_2 \frac{(V_2-V_0)}{h} \times \frac{h}{2} + \in_2 \frac{(V_3-V_0)}{h} \times h + \in_2 \frac{(V_4-V_0)}{h} \times \frac{h}{2} + \in_1 \frac{(V_4-V_0)}{h} \times \frac{h}{2} \tag{3.13}$$

On rearranging finally we get

$$V_0 = \frac{\in_1}{2(\in_1+\in_2)} V_1 + \frac{\in_2}{2(\in_1+\in_2)} V_3 + \frac{1}{4} V_2 + \frac{1}{4} V_4 \tag{3.14}$$

On the line of the symmetry, after imposed the conditions

$$\frac{\partial V}{\partial n} = 0 \tag{3.15}$$

Thus symmetrical along x axis:

$$V_0 = 1/4[2V_1 + V_2 + V_4] \tag{3.16}$$

And along y axis:

$$V_0 = 1/4[V_1 + V_3 + 2V_4] \tag{3.17}$$

The characteristic impedance $Z_0$ and phase velocity $u$ of the line are defined as

$$Z_0 = \sqrt{L/C} \text{ And } u = 1/\sqrt{LC} \tag{3.18}$$

Where $L$ and $C$ are the inductance and capacitance per unit length, respectively.

If the dielectric medium is nonmagnetic ($\mu = \mu_0$), the characteristics impedance $Z_{00}$ and phase velocity $u_0$ is given by

$$Z_{00} = \sqrt{\frac{L}{C}}_0 \text{ And } u = 1/\sqrt{LC}_0 \tag{3.19}$$

Where $C_0$ is capacitance per unite length without dielectric. Thus we can define as

$$Z_0 = \frac{1}{u_0\sqrt{CC_0}} = \frac{1}{uC} \text{ And } u = \frac{u_0}{\sqrt{\varepsilon_{eff}}} \tag{3.20}$$

$$\varepsilon_{eff} = C/C_0 \tag{3.21}$$

If the $V_d$ is the potential difference between the inner and outer conductor,

$$C = 4Q/V_d \tag{3.22}$$

So that we have to find charge per unite Q , which can be calculated by

$$Q = \oint_L D.dl = \oint_L \varepsilon\frac{\partial V}{\partial n}\, dl \tag{3.23}$$

We take a problem statement i.e. based on the transmission line in which we have to find the characteristics impedance $Z_0$ , given that dimensions of 2.5cm x 2.5cm, d=0.5cm, w=1cm, t=0.001cm, $\varepsilon_1 = \varepsilon_0, \varepsilon_2 = 2.35\varepsilon_0$. after solving this we get the $Z_0$ From Formula 64.3352 Ω and from simulation as following given in Table 3.1.

Table 3.1: Characteristics Impedance at different no of iteration and step sizes

| h | Number of Iterations | $Z_0(\Omega)$ |
|---|---|---|
| 0.25 | 700 | 57.1756 |
| 0.1 | 500 | 61.5025 |
| 0.05 | 500 | 68.4747 |
| 0.05 | 700 | 65.2688 |
| 0.05 | 1000 | 63.4 |

## 3.4 The Finite-Difference Time-Domain Method

This section presents the substance of the finite difference time-domain method and the derivation of the algorithm used in this work. The derived algorithm follows indeed closely that confirmed by Yee in 1966 , which is the element for FDTD electromagnetic field simulation. Despite its age and the original appearance of different formulations a well known as ADI-FDTD and MRTD , Yee's algorithm likewise remains the primary choice for FDTD, due to its robustness and simplicity

### 3.4.1 Maxwell's Equations in 2D Dimensions

The Maxwell's equations is a time-dependent in which it is a part of space without imposed electric or magnetic current sources, for all that take care of have materials that absorb electric or magnetic field energy, are supposing in differential form, by

$$\int \mathrm{Edl} = -\frac{\mathrm{d}}{\mathrm{dt}}\int \mathrm{B_n dA} - \mathrm{J}_m \qquad (3.24)$$

$$\int Hdl = J + \varepsilon_o \frac{d}{dt}\int E_n dA \tag{3.24}$$

$$\int D \times dA = \rho \tag{3.25}$$

$$\int B \times dA = \rho_m \tag{3.26}$$

Where,

E: Electric Field (V/m);

H: Magnetic Field (A/m);

D: Electric Flux Density (C/$m^2$);

B: Magnetic Flux Density (Wb/$m^2$);

J: Electric Current Density (A/$m^2$);

$\rho$: Free Electric Charge Density (C/$m^3$);

$J_m$: Equivalent Magnetic Current Density (V/$m^2$);

$\rho_m$: Free Magnetic Charge Density (Wb/$m^3$);

It is imperative to say that that magnetic charge density and conductivity are non-physical amounts. Since magnetic charges have not yet been seen in Nature. By and by, these amounts are numerically valuable to actualize Perfectly Matched Layer Absorbing Boundary Conditions; what's more, their consideration does not build the computational necessities of the calculation. For the determination of the FDTD calculation utilized as a part of this work just tensors will be considered,

$$\varepsilon_r = \begin{bmatrix} \varepsilon_{xx} & 0 & 0 \\ 0 & \varepsilon_{yy} & 0 \\ 0 & 0 & \varepsilon_{zz} \end{bmatrix} \tag{3.27}$$

$$\mu_r = \begin{bmatrix} \mu_{xx} & 0 & 0 \\ 0 & \mu_{yy} & 0 \\ 0 & 0 & \mu_{zz} \end{bmatrix} \tag{3.28}$$

$$\sigma = \begin{bmatrix} \sigma_{xx} & 0 & 0 \\ 0 & \sigma_{yy} & 0 \\ 0 & 0 & \sigma_{zz} \end{bmatrix} \tag{3.29}$$

$$\sigma^* = \begin{bmatrix} \sigma_{xx}^* & 0 & 0 \\ 0 & \sigma_{yy}^* & 0 \\ 0 & 0 & \sigma_{zz}^* \end{bmatrix} \tag{3.30}$$

By writing the curl components of above equation in Cartesian coordinates one gets the following arrangement of six coupled scalar equations:

$$\frac{\partial E_x}{\partial t} = \frac{1}{\varepsilon_0 \varepsilon_{xx}} \left[\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} - \sigma_{xx} E_x\right]$$

$$\frac{\partial E_y}{\partial t} = \frac{1}{\varepsilon_0 \varepsilon_{yy}} \left[\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} - \sigma_{yy} E_y\right]$$

$$\frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon_0 \varepsilon_{zz}} \left[\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} - \sigma_{zz} E_z\right] \tag{3.31}$$

$$\frac{\partial H_x}{\partial t} = \frac{1}{\mu_0 \mu_{xx}} \left[\frac{\partial E_y}{\partial z} - \frac{\partial E_z}{\partial y} - \sigma_{xx}^* H_x\right]$$

$$\frac{\partial H_y}{\partial t} = \frac{1}{\mu_0 \mu_{yy}} \left[\frac{\partial E_z}{\partial x} - \frac{\partial E_x}{\partial z} - \sigma_{yy}^* H_y\right]$$

$$\frac{\partial H_z}{\partial t} = \frac{1}{\mu_0 \mu_{zz}} \left[\frac{\partial E_x}{\partial y} - \frac{\partial E_y}{\partial x} - \sigma_{zz}^* H_z\right]$$

The past six equations form the premise of the FDTD technique. By discretizing them using finite-differences, it is conceivable to get a numerical algorithm that models three-dimensional electromagnetic field wonders [17].

## 3.4.2 The Yee Algorithm

**The Yee cell and the leapfrogging scheme**

It is essential to notice that in the Gauss' Law relations in Maxwells equations are verifiable in the set of above equations that may not as a matter of course remain constant for a subjective discretization of this set. This implies the sampling point on the grid for the E and H field parts must be situated in a manner that the numerical space-subordinate operations of the curl operator in which Gauss' laws is enforce. In year 1966, Yee proposed a gridding plan that fulfilled this prerequisite and later turned out to be generally known as the Yee cell, whose structure is appeared in Fig. 3.8.

As can be found in Fig. 3.8, Yee's gridding plan positions its field segments such that each E part is encompassed by four flowing H segments and every H segment is encompassed by four coursing E segments, along these lines imitating Ampere's Law and Faraday's Law at the network level. Actually, Yee's plan recreates both the pointwise differential structure and the perceptible fundamental type of Maxwell's equations [17],[19].

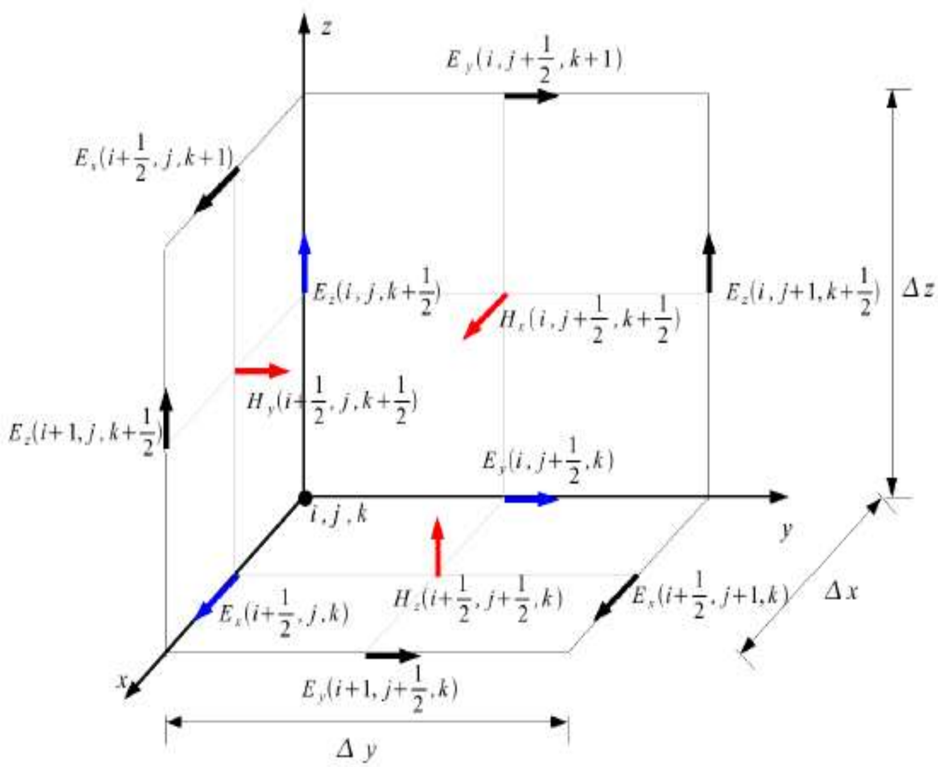



Figure 3.8: Yee's Grid

Figure 3.8 position of the electric and magnetic field vector components about the cell (i,j,k) of the Yee space lattice. Only the electric field components in blue and the magnetic field components in red belong to the cell (i,j,k).

Taking into account this gridding scheme, Yee discretized an adaptation of the arrangement of above equation. Particularized for lossless isotropic media utilizing central-difference expressions, for both space and time derivative. The way that central-difference expressions, having $2^{nd}$ order exactness, are more precise than either forward or in reverse differences, extraordinarily adds to the robustness of the Yee calculation. A standout amongst the most imperative qualities of the Yee's calculation, coming about because of its focal distinction plan, is the course of action of E and H parts in time in a jump design. This implies the E segments for a period t are Figured from already put away H parts that compare to a period t − t/2, where t is the time-step. At that point the H parts for time t + t/2 are Figured from the put away E segments for time t. This trademark makes the calculation completely express, evading issues like concurrent conditions and reversal of enormous networks

## 3.4.3 The Two Dimensional FDTD Models

The FDTD method discretizes Maxwell equations using finite-difference approximations, directly in the time domain, in which replacing its derivatives. It is basic, easy to code, but has the iterative solution. It is hence conditionally stable: one needs to fulfill the stability condition. The FDTD volume is finite, and therefore, may model only closed regions. An important task in FDTD is the Free-space simulation, and various effective boundary terminations have been developed for the last two decades. Broadband (pulse) excitation is possible in the FDTD but inherits the numerical dispersion problem. Finally, only near fields can be simulated around the object under investigation; far fields can be extrapolated using the Equivalence Principle (e.g., the Stratton-Chu equations) [17],[19], [28].

### 3.4.3.1 First-Order Coupled Equations

The supposition of a consistent translational symmetry along z reduces the three dimensional issue into two measurements on the x-y plane. Maxwell conditions in such a situation are characterized with three parameters (the permittivity ε, penetrability μ, and conductivity σ ).The discretized FDTD iteration equation reduce to two sets of scalar equation [28].

**Set ♯ 1**: $\boldsymbol{TM_z(H_z = 0)}$

$$H_x^n(i,j) = H_x^{n-1}(i,j) - \frac{\Delta t}{\mu_0}\left[\frac{E_z^n(i,j) - E_z^n(i,j-1)}{\Delta y}\right] \tag{3.32}$$

$$H_y^n(i,j) = H_y^{n-1}(i,j) + \frac{\Delta t}{\mu_0}\left[\frac{E_z^n(i,j) - E_z^n(i-1,j)}{\Delta x}\right] \tag{3.33}$$

$$E_z^{n+1}(i,j) = \left(\frac{2\varepsilon-\sigma\Delta t}{2\varepsilon+\sigma\Delta t}\right) E_z^n(i,j) + \frac{2\Delta t}{2\varepsilon+\sigma\Delta t}\left[\frac{H_y^n(i,j) - H_y^n(i-1,j)}{\Delta x}\right] - \frac{2\Delta t}{2\varepsilon+\sigma\Delta t}\left[\frac{H_x^n(i,j) - H_x^n(i,j-1)}{\Delta y}\right] \tag{3.34}$$

**Set ♯ 2:** $\boldsymbol{TE_z(E_z = 0)}$

$$E_x^n(i,j) = \left(\frac{2\varepsilon-\sigma\Delta t}{2\varepsilon+\sigma\Delta t}\right) E_z^{n-1}(i,j) - \frac{2\Delta t}{2\varepsilon+\sigma\Delta t}\left[\frac{H_z^n(i,j) - H_z^n(i,j-1)}{\Delta y}\right] \tag{3.35}$$

$$E_y^n(i,j) = \left(\frac{2\varepsilon-\sigma\Delta t}{2\varepsilon+\sigma\Delta t}\right) E_z^{n-1}(i,j) - \frac{2\Delta t}{2\varepsilon+\sigma\Delta t}\left[\frac{H_z^n(i,j) - H_z^n(i-1,j)}{\Delta x}\right] \tag{3.36}$$

$$H_z^n(i,j) = H_z^{n-1}(i,j) + \frac{\Delta t}{\mu_0}\left[\frac{E_y^n(i,j) - E_y^n(i-1,j)}{\Delta x}\right] - \frac{\Delta t}{\mu_0}\left[\frac{E_x^n(i,j) - E_x^n(i,j-1)}{\Delta y}\right] \tag{3.37}$$

### 3.4.3.2 Second order Decoupled Differential equation

Two of the three field components in Equations (3) and (4) can be eliminated, and a second-order differential (wave) equation with a single field component can be obtained. For example, the following wave equation for the TMz problem can be directly obtained from Equation 3.32 [28].

Wave equation for TM mode

$$\left[\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} - \varepsilon\mu \times \frac{\partial^2}{\partial t^2} - \sigma\mu\frac{\partial}{\partial t}\right] E_z = 0 \tag{3.38}$$

This equation is, defined for

$$t \geq 0;\ 0 \leq x \leq X_{max};\ 0 \leq y \leq Y_{max} \tag{3.39}$$

Together with the boundary condition

$$E_z(0, \mathrm{y}, \mathrm{t}) = g_1(\mathrm{y}, \mathrm{t}) \text{ for x = 0, } 0 \leq y \leq Y_{max}$$

$$E_z(\mathrm{x}, 0, \mathrm{t}) = g_2(\mathrm{x}, \mathrm{t}) \text{ for y = 0, } 0 \leq x \leq X_{max}$$

$$E_z\,(X_{max}, \mathrm{y}, \mathrm{t}) = g_3(\mathrm{y}, \mathrm{t}) \text{ for x = } X_{max},\ 0 \leq y \leq Y_{max}$$

$$E_z(0,\ Y_{max}, \mathrm{t}) = g_4(\mathrm{x}, \mathrm{t}) \text{ for y = } Y_{max},\ 0 \leq x \leq X_{max} \tag{3.40}$$

And initial conditions

$$E_z(x, y, 0) = f_1(x, y)$$

$$\frac{\partial E_z(x,y,0)}{\partial x} = f_2(x, y)$$

The FDTD discretized form of equation (3.38) is

$$E_z^{n+1}(i,j) = \frac{4(1-p-q)}{g} E_z^n(i,j) - \frac{t}{g} E_z^{n-1}(i,j) + \frac{2p}{g}[E_z^n(i-1,j) + E_z^n(i+1,j)]..$$

$$+ \frac{2q}{g}[E_z^n(i,j-1) + E_z^n(i,j+1)] \tag{3.41}$$

where

$$\mathrm{p} \triangleq \left(\frac{v\Delta t}{\Delta x}\right)^2,\ \mathrm{q} \triangleq \left(\frac{v\Delta t}{\Delta y}\right)^2$$

$$\mathrm{g} \triangleq 2+\mu\sigma v^2\Delta t,\ \mathrm{t} \triangleq -2+\mu\sigma v^2\Delta t$$

$$\mathrm{v} = \frac{1}{\sqrt{\varepsilon\mu}} \tag{3.42}$$

The values at the first two time instants of $E_z$(i.e $E_z^0(i,j)$ and $E_z^1(i,j)$) must be supplied for the spatial source injection.

## 3.5 Analysis of Microstrip Lines using FDM

We simulates the voltage distribution of a microstrip line as shown in below Figure. Allow the user to input the dimensions ($W$ and $d$) of the microstrip as well as the dielectric constant $\varepsilon_r$ of the substrate and the voltage difference $V_0$ between the top conductor and the ground plane.

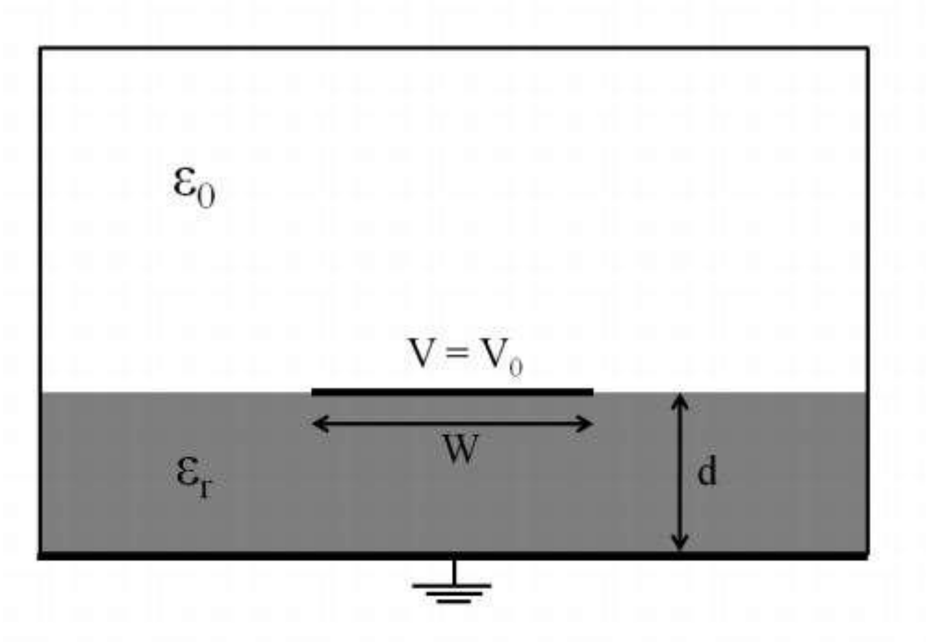
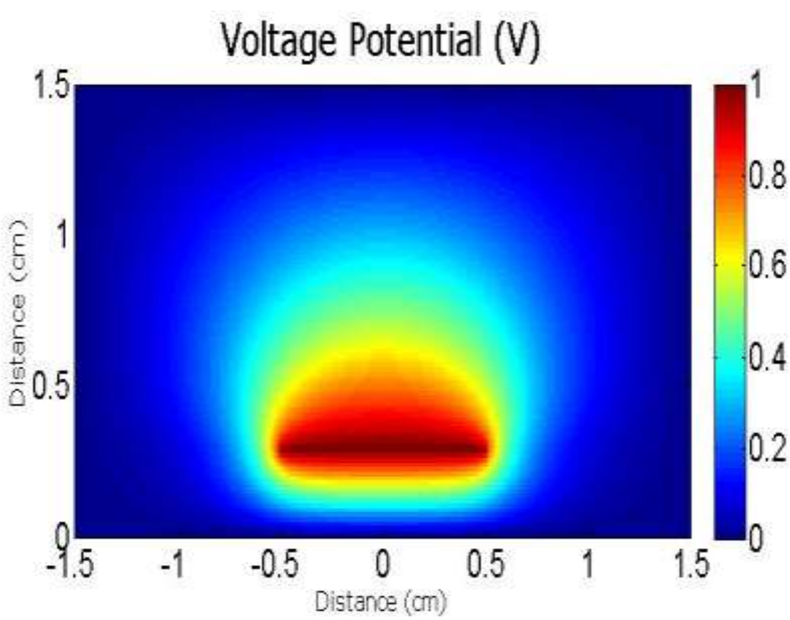
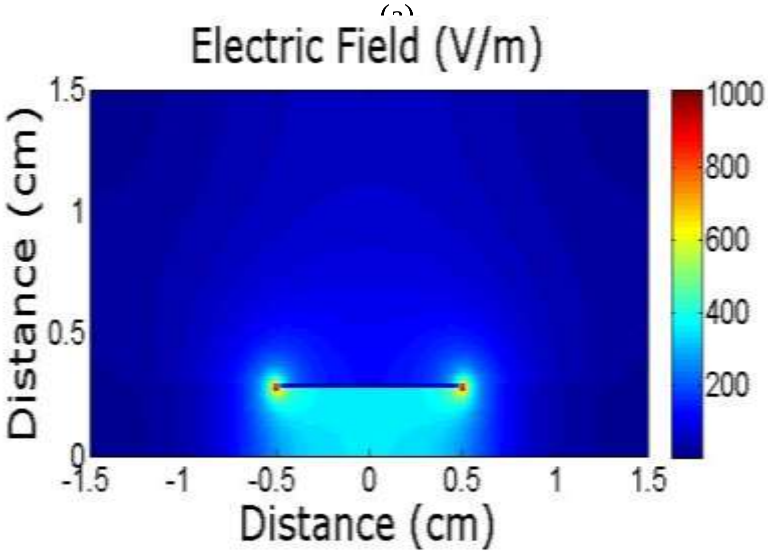



Figure 3.9: Microstrip line structure

Let us take dimensions $W$ = 1.0 cm, $d$ = 3.0 mm, $\varepsilon_r$= 3,V=1.0 V . As we applying Dirichlet Boundaries Conditions using FDM. We get the voltage distribution and the electric field distribution over the micro strip line. We get the characteristics impedance of 41.6 ohm by analytical method and by using simulation 40.4 ohm [20].






(b)

Figure 3.10: (a) Voltage Distribution and (b) Electric field distribution

As we increase the width of microstip lines the characteristic impedance of the line is decreases simultaneously. Here in below Figure shows that the graph using both analytical and simulated method [20].

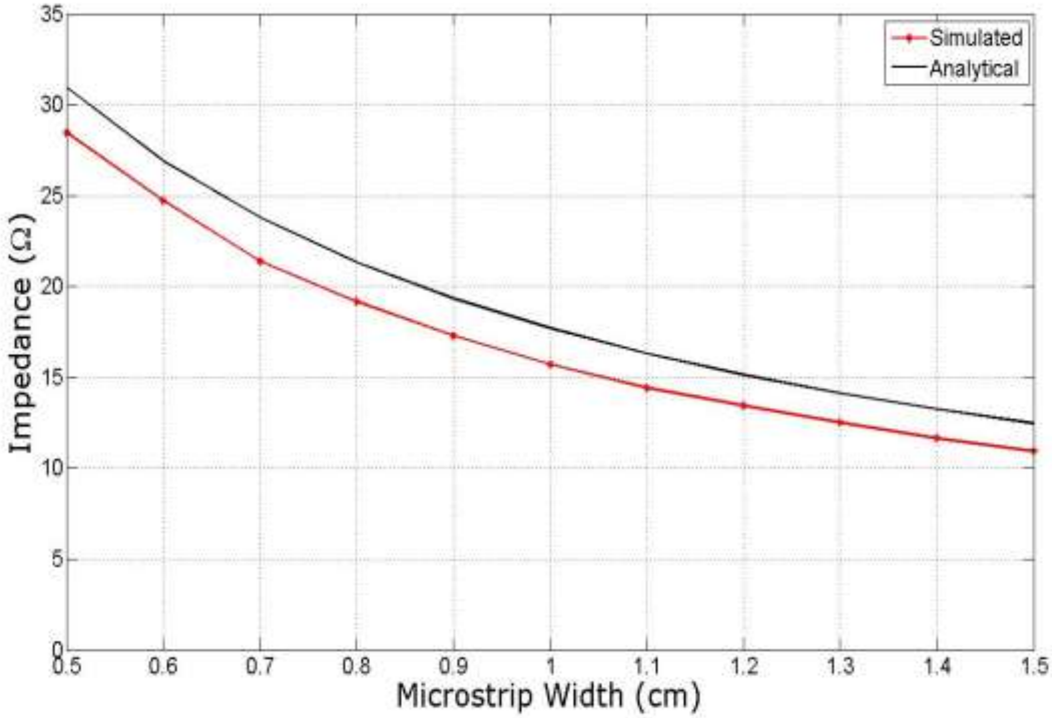



Figure 3.11: Graph between the Impedance and the Microstrip width

Notice that the both behave pretty similar but with a slight error between them. This is to be expected from when compared against analytical solutions.

## 3.6 Summary:

In this chapter what is computation electromagnetic, its advantage, types and the finite difference method is discussed. Under finite difference method its types, advantage and the finite difference scheme, and Laplace equation is analyzed. The microstrip line characteristics impedance is calculated using the finite difference method is done. Another part we studied the yee's algorithm for solving the equation using FDTD.

# Chapter 4

# Filtenna for X-Band and Cognitive Radio Applications

## 4.1 Filtenna for UWB and X-band application

### 4.1.1 Introduction:

Ultra-wideband (UWB) innovation has picked up a consideration among the academic world and modern in wireless universes for the utilization of indoor and hand held-framework. In 2002, UWB innovation has grown a ton of fame since US federal Commission Communication (FCC) allowed 3.1-10.6 GHz bands of frequency for commercial utilization. UWB techniques correspondence innovation offers high information rate transmission and minimal size low power utilization, simple to manufacture offers points of interest to the correspondence applications, for example, RFID frameworks, sensor systems, radar, and location tracking. There are different types of UWB antenna however planar monopole antenna is widely utilized because of the minimal effort, simple to manufacture and light weight [21].

A few outline methods are proposed to implement the band-rejection attributes for UWB antenna, e.g. cutting a slot in transmitting patch. The shape that has been proposed are bend slot, square, and H-molded shapes. Others techniques are utilizing meandered lines structure and including parasitic components [22].

Here filtenna is designed from incorporating UWB antenna with bandstop component into one structure. The rejected band that cover X-band is created by presenting open stub resonator with bandstop filter response.

### 4.1.2 Proposed Filtenna Structure

For designing the filtenna first we designed the filter which having band-rejection characteristics. As shown in Figure 4.1 the structure of the filter having one open stub. To achieved reject-band by use of open stub with stub length of λg/4, where λg is guided wavelength of the microstrip line at the center frequency. The rejected-bands are controlled by the dimensions of the open stub. Figure 4.1 demonstrates the comparable circuit of the open stub structure that has been used as the component to reject the undesirable band.

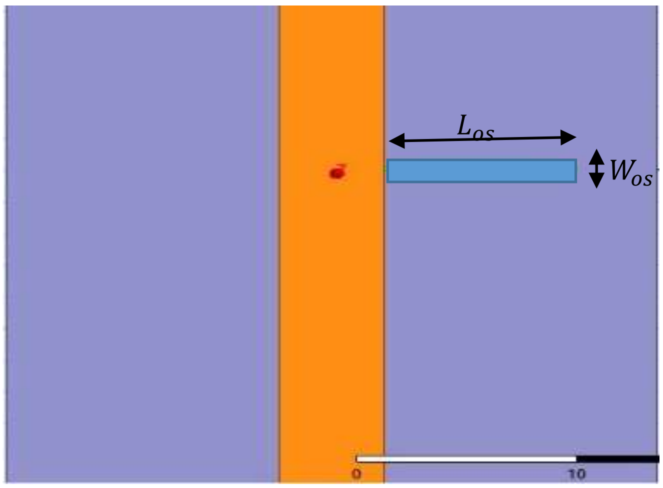



Figure 4.1: The Proposed Band-rejection Filter


Figure 4.2 The Equivalent Circuit of the Open-ends

The geometry of the proposed filter consist of the fed with 50Ω microstip line on one side of the substrate and partial ground plane on opposite of the substrate which is perfect E sheet. To implement a band-rejection an open stub are utilized in the feedline to get desired application with dimension of Wos x Los. The filter is designed on the RT/Duriod having relative permittivity $\varepsilon_r = 2.2$ and thickness of 1.6 mm [22],[23].

The open stub length can be obtained by the following formula:

$$L = \frac{c}{4f\sqrt{\frac{\varepsilon_{r+1}}{2}}} \tag{4.1}$$

Where $\varepsilon_r$ the dielectric constant, c is the speed of the light in the free space and f is the center frequency of the desired rejected band.

To design filtenna we integrated this filter with the Monopole antenna .The filtenna structure as shown in Figure 4.3 is designed on the RT/Duroid having relative permittivity $\varepsilon_r = 2.2$ , thickness h=0.8mm, and highlights an partial rectangular ground plane. A tapered matching segment was joined between the patch of filtenna and its food line with a specific end goal to accomplish better impedance matching [24]. The distinctive geometric parameters of the filtenna are delineated in Table 4.1.

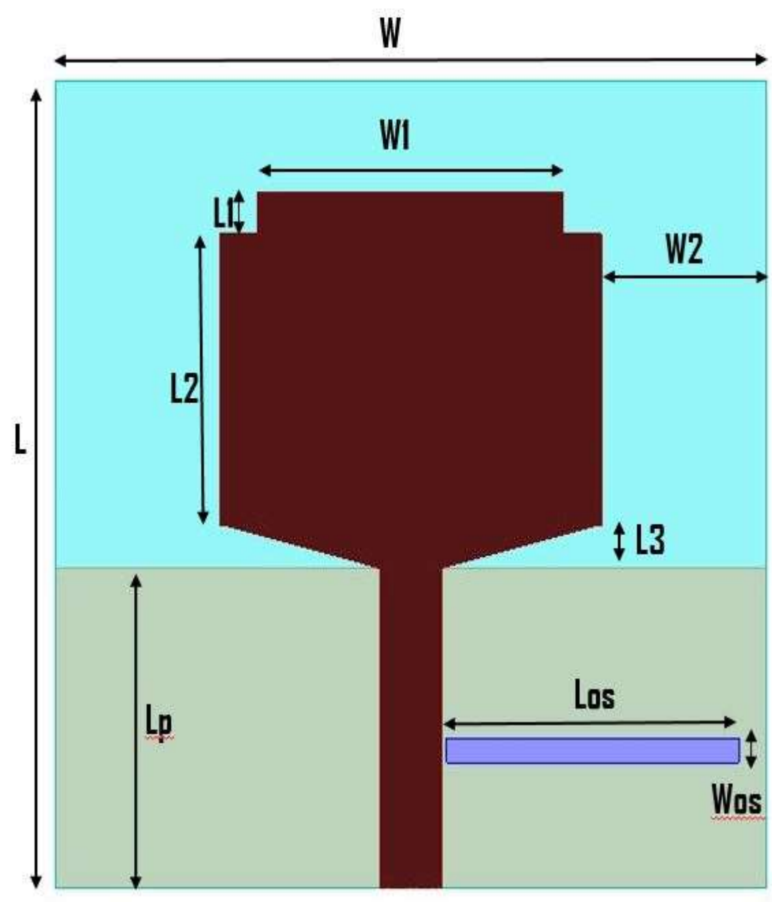



Figure 4.3: The geometry of the proposed filtenna

Table 4.1:. Design Parameter of proposed Filtenna

| **Parameters** | **Value(mm)** | **Parameters** | **Value(mm)** |
|---|---|---|---|
| W | 28 | L | 29 |
| L1 | 1.5 | L2 | 10.5 |
| L3 | 1.5 | W1 | 12 |
| W2 | 6.5 | Lp | 11.5 |
| Los | 11.5 | Wos | 0.9 |

## 4.1.3 Results and Discussion

The Performance of the proposed Filtenna is concentrated on utilizing Ansoft HFSS simulation tool. The open stub resonator length is optimized to get the ideal bandstop channel response.

Figure 4.4 demonstrates the impact of the variation on the length of the open stub (Los). As appeared in the Figure the center frequency of proposed filter is influenced by the length of the open stub. As the length of the open stub increase, the insertion loss is moved to one side or to the lower frequency. The explanation of this conduct is that increment of the length of the open stub results in an expansion in equivalent reactive components of the structure and proposed filter turn out to be more capacitive this turns leads to a decrease in the resonance frequency of the insertion loss.

Fig.4.5 indicates the impact of the open stub's width on the performance of the filter. As expansions in the width of the stub lead to the widening bandwidth of the rejected band and the resonance frequency is moved to one side.

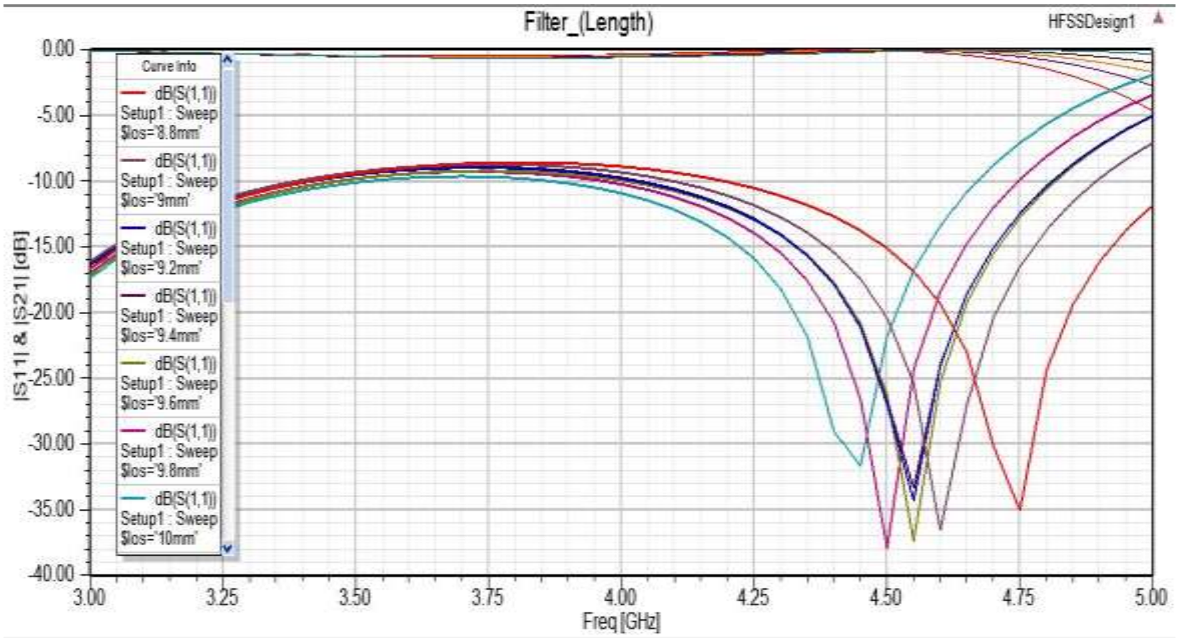



Figure 4.4: Reflection and insertion loss with variation of the length of the open stub.

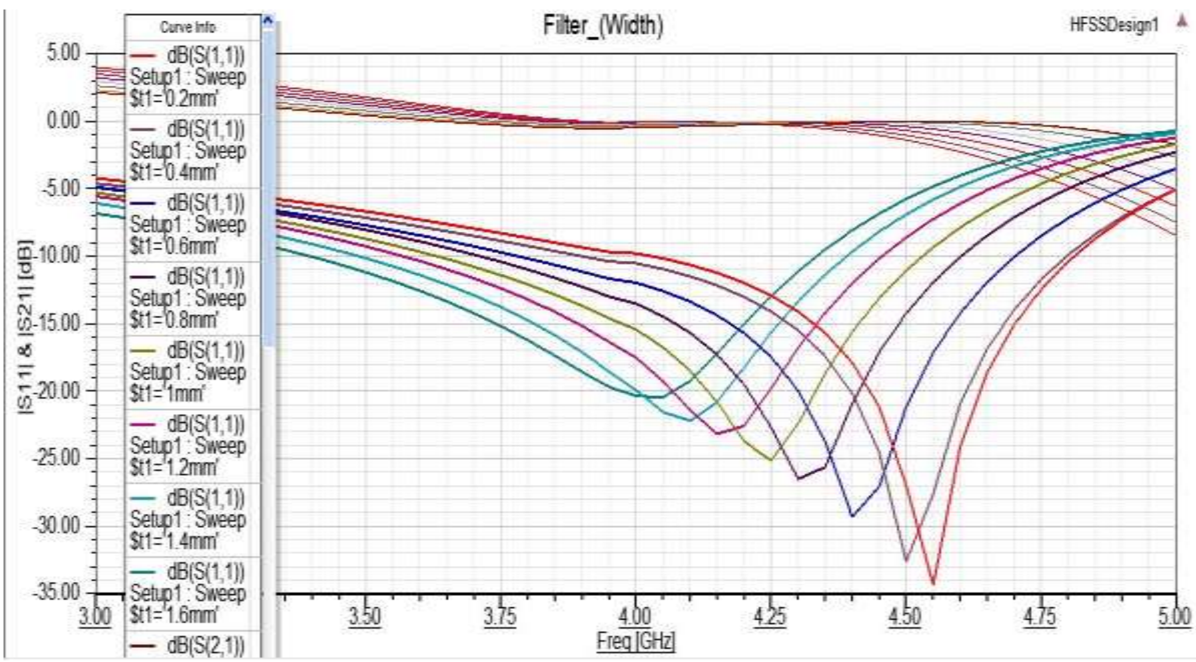



Figure 4.5: Reflection and insertion loss with variation of the width of the open stub.

Figure 4.6 shows the proposed Filtenna without the open stub the reflection coefficient ≪-10dB over the 4-15.5 GHz band. After introduce the Open stub in that we are achieve the reflection at

X-band and other band is rejected due to open stub. Figure 4.7 shows the 3D radiation pattern of the proposed Filtenna. It can be seen that the radiation pattern at 11.5 GHz and gain is 4.3dB.

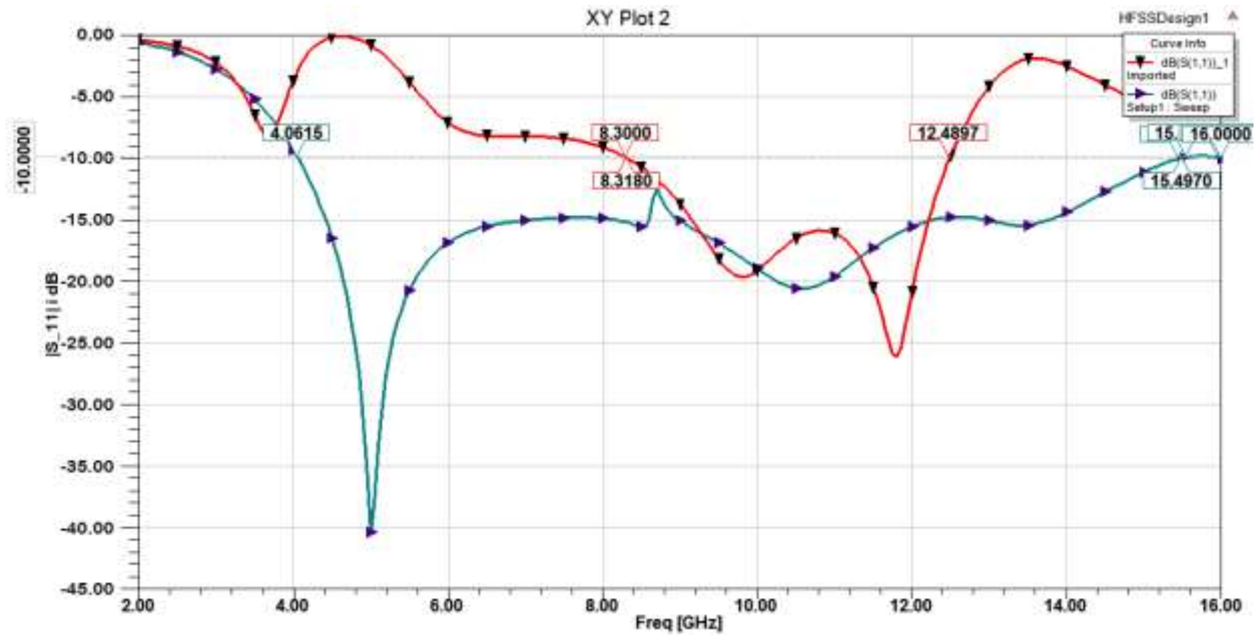



Figure 4.6: Reflection of the proposed Filtenna

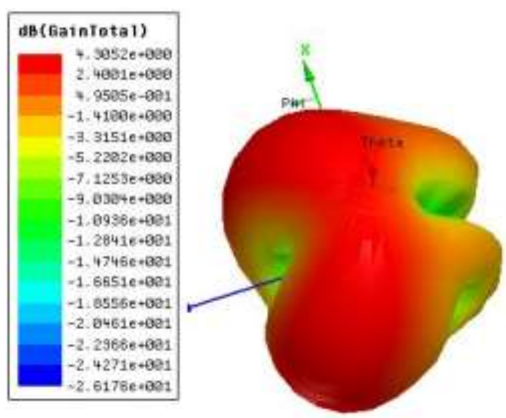



Figure 4.7: The radiation Pattern of the proposed filtenna at 11.5 GHz

# 4.2 Varactor-based Filtenna for Cognitive Radio applications

## 4.2.1 Introduction

With the progression in wireless technologies, there is a tremendous interest to actualize antenna that is smart to tune their operating characterstics (frequency, polarization, radiation pattern) as indicated by the perpetually changing correspondence necessities. In addition, utilizing various committed antennas to cover each of the diverse wireless services that are scattered over a wide frequency groups builds the system cost, the space necessities for the antennas, and their isolation. Reconfigurable antennas, similar to the one proposed here, are the potential possibility for future RF front-end solution for minimizing the quantity of antennas required in a specific system [2].

Reconfigurable antennas have been broadly examined all through the most recent two decades. This types of antennas require switching components to change the antenna's electrical properties and also its radiation patterns. Electrically reconfigurable antenna uses RF-MEMS, p-i-n diodes, or varactors to perform the required tunability in the antenna functionality.

By adding reconfigurability to the filter operation, the nonlinearities created by the switching components and additionally the filter's insertion loss ought to be tended to given that the filter constitutes one of the fundamental blocks in any transmitter or receiver RF chain .

In a Cognitive Radio (CR) framework, there is a requirement for an antenna to be utilized for monitoring the spectrum (detecting), and communication over a picked white space (communication). At the point when utilized for communication, the antenna must be frequency reconfigurable, to be tuned to the band chose for operation [2].

A cognitive radio is equipped for detecting whether a particular frequency band is being allocated to a particular client or terminal. If the frequency band was found idle, then a communicating antenna is tuned to telecast over that frequency. This enhances the r utilization efficiency and permits the frequency bands to be constantly assigned to various clients. In the event that the approved terminal (essential user) restarted transmission, the optional terminal jumped off into an alternate band, or adjusts its transmission power level, modulation plan, or its antenna' radiation patterns, while staying in the same frequency band, to suppress interference .

Many techniques have been used in literature to design frequency reconfigurable antennas. An efficient technique is based on incorporating tunable band-pass filters into wideband antennas; thus creating filtennas. Reconfigurable filtennas achieve frequency tuning without distorting their radiation patterns. The proper incorporation of a well-suited tunable bandpass filter into a wideband antenna is essential to preserve its radiation performance. It is also important to mention that tuning the band-pass filter requires appropriate biasing [26].

In proposed design a varactor-tuned filtenna for overlay cognitive radio applications is presented. The proposed technique is based on integrating a varactor-tuned coupled-line band-pass filter into the feed line of a wideband antenna to achieve frequency tuning without disturbing its radiation characteristics.

### 4.2.2 Geometry of the Filtenna

The configuration of the proposed filter is shown in Fig.4.8. The proposed band-pass filter structure is implemented on an RO3006 with dielectric constant of 6.15 and thickness of 1.28mm. The filter's total dimensions are $70 \times 32.5\ mm^2$. The band-pass filter reconfigurability is achieved by fusing an SMV 1405 [27], a varactor from SkyWorks, within its structure. The filter is based on band-pass filter structure that integrated with the feed of the antenna.

The corresponding filter's microstrip line is made out of three segments. first section of microstrip line having length of 11 mm and a width of 1.74 mm, which having an impedance of $50\Omega$. The band-pass structure is designed in center of microstrip line section.

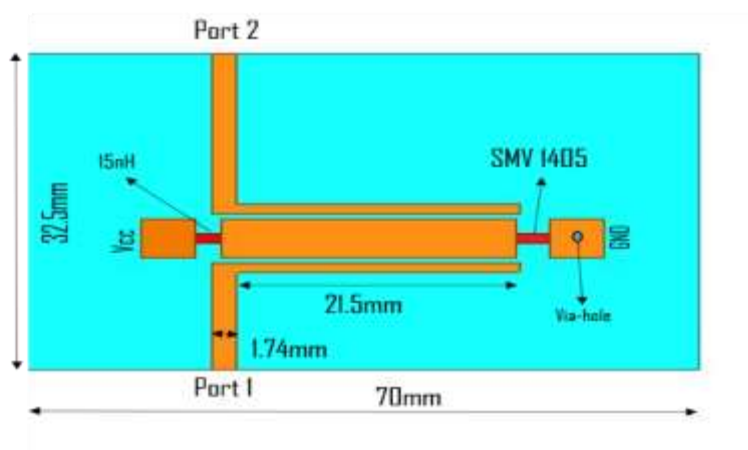


Figure 4.8: Tunable Filter Structure

The bans-pass structure having 22.5 mm physical length of resonator corresponding to an electrical length of half wavelength at 2.75 GHz. That is calculated by the formula

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \tag{4.2}$$

When the resonator is open-circuited (loading capacitance, $C_L = 0$ ), a band-pass resonance for the filter is attained at the same frequency. The tuning of the reverse voltage across the loading varactor will result in tuning the electrical length of the resonator. Thus, frequency tuning is achieved [26]. As the applied reverse voltage across the varactor decreases, the loading capacitance increases to achieve resonance at lower frequencies.

The integration of a tunable coupled line band-pass filter into the feed of an 80 x $70mm^2$ wideband antenna makes up the configuration of the presented tunable filtenna. It is fed with 50 Ω microstrip line that corresponds to a width of 1.74 mm with partial rectangular ground plane as shown in Figure.4.9. The fabricated Filtenna as shown in Figure 4.10.

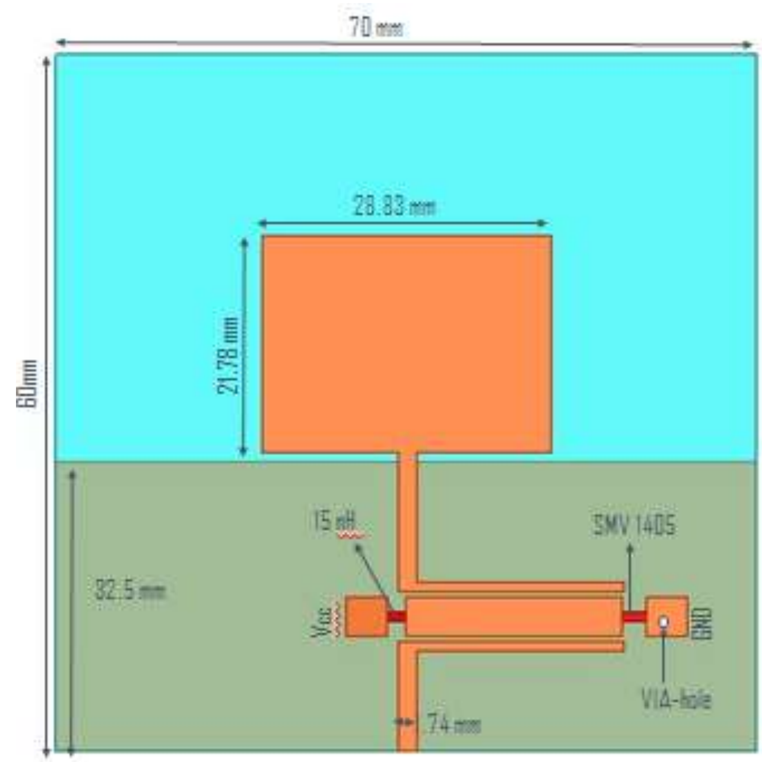



Figure 4.9: Tunable Filtenna Structure

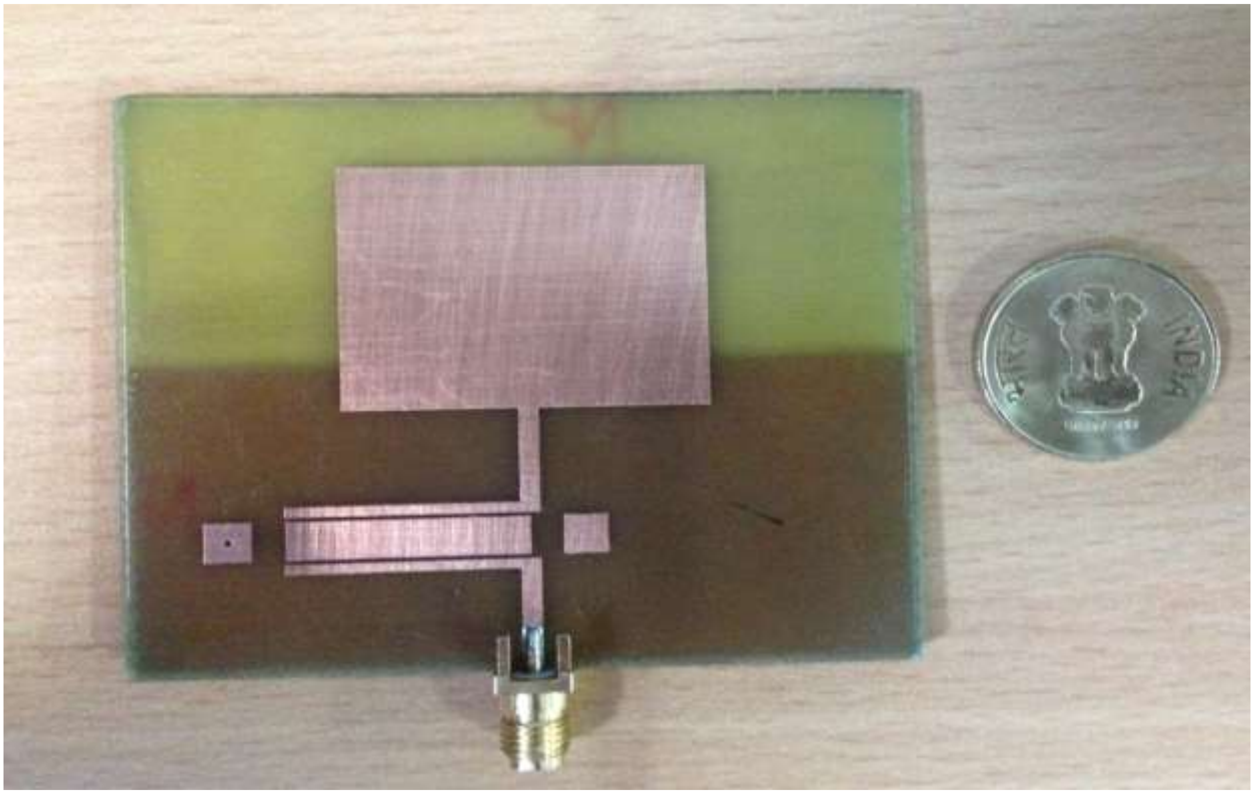



Figure 4.10: Fabricated Design of the Filtenna

For the purpose of achieving frequency tunability, a varactor is incorporated into configuration, as indicated. Changing the varactor's capacitance changes the pass-band frequency region.

### 4.2.3 Results and Discussion

The proposed tunable filtenna is designed using Ansys HFSS 15. The biasing network of the varactor is simple, and does not reside on the filtenna radiating patch. i.e. the block responsible for tuning the resonant frequency of the filtenna does not disturb its radiation performance. As illustrated in Figure 4.12, a 15nH RF choke is incorporated to prevent any RF leakage to DC supply. The other terminal of the contained band-pass filter's resonator is grounded through a via-hole. Accordingly, the applied reverse voltage adjusts the electrical length of the resonator to tune the operational frequency of the presented filtenna. The reflection coefficients of the tunable filter for several reverse voltage levels are shown in Fig. 4.11 and group delay in fig. 4.12 .

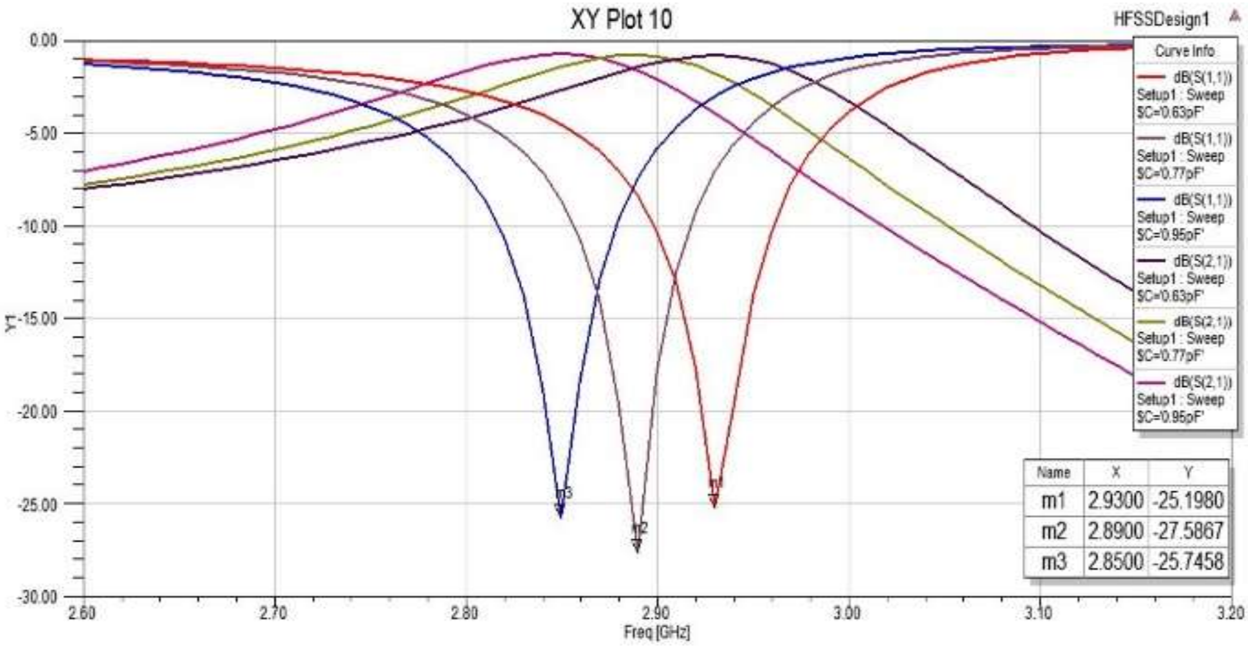



Figure 4.11: Reflection coefficient and Transmission Coefficient of Filter


Figure 4.12: Group Delay of the tunable filter

It's worth mentioning here that the reassembly of the incorporated bandpass filter, with the number of mounted varactors increased. And fig 4 shows the reflection coefficients of the tunable filtenna for various reverse voltages shown in Figure 4.12. In reflection coefficient of filtenna we are here varying the capacitor values of the SMV 1405 varactor diode according to which we measure refection coefficients at different voltages value. They shows the narrow band tunability over 2.85-2.95 GHz, for the capacitance value between 0.63pF-0.95pF.

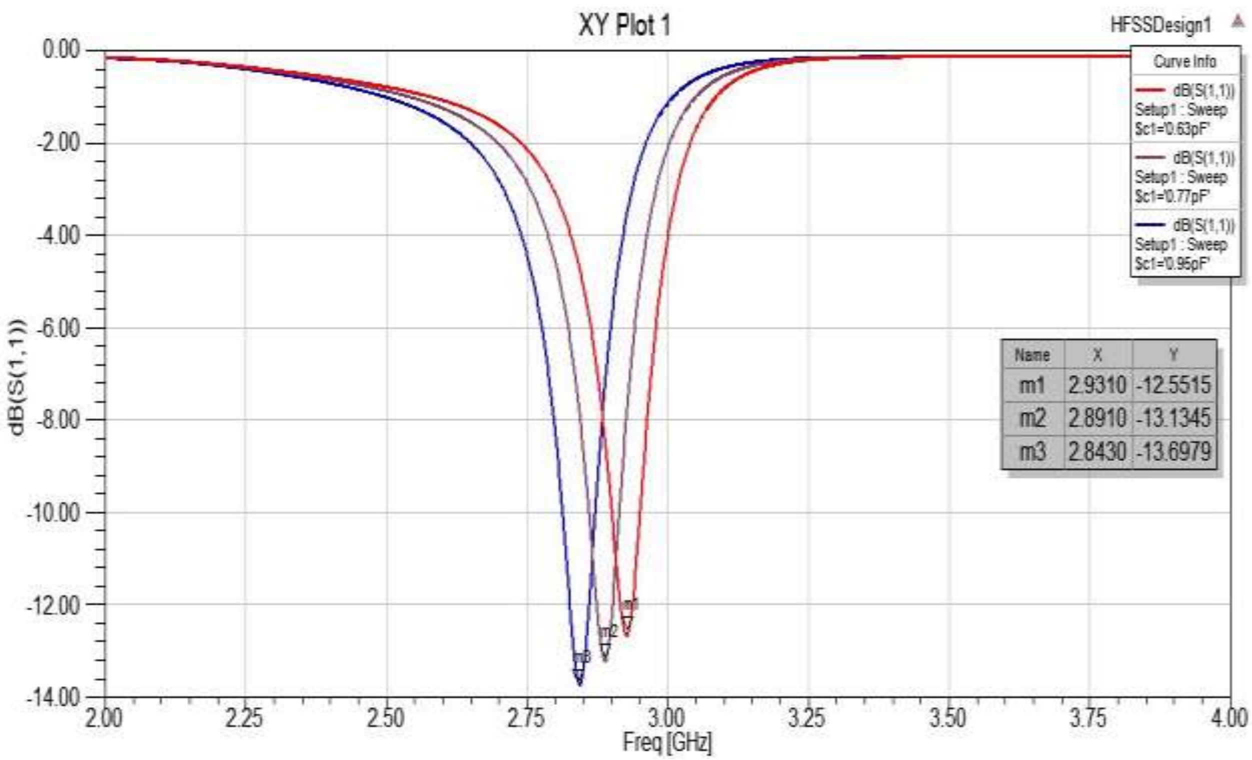
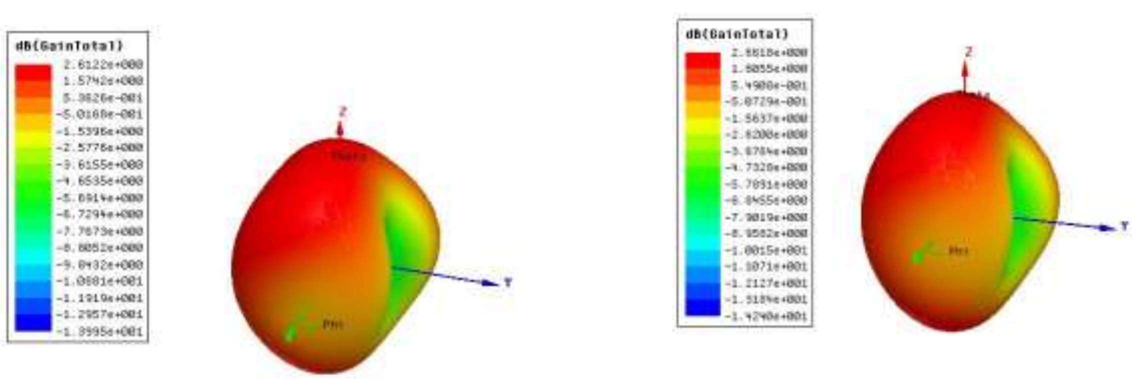
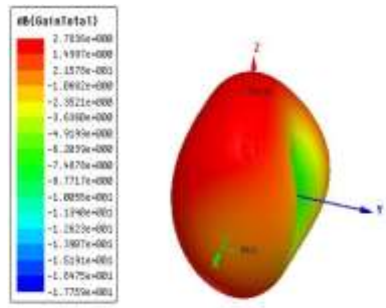



Figure 4.13: Reflection Coefficient of the Tunable Filtenna



(a) (b)



(c)

Figure 4.14: Gain 3D-Polar Plot (a) for 0.63pF (b) 0.77pF (c) 0.95pF

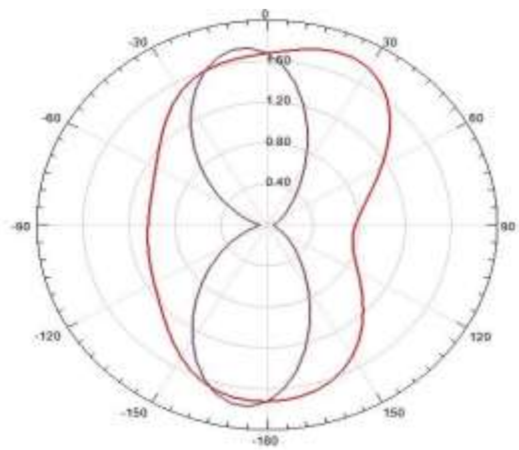



Figure 4.15: Radiation Pattern Directivity

The normalized gain 3D polar plot for different values of capacitance values are shown in Figure 4.14. The radiation pattern of the filtenna omnidirectional approximately as shown in fig 4.15. And we achieved gain of 2.7 dB at 2.75GHz and directivity of 1.6. Moreover, a greater than 75 % radiation efficiency Figure is revealed at the same operating frequency.

## 4.3 Summary:

In this chapter two filtenna designs are proposed. In first part of design of filtenna, the introduction of UWB and X-band with the geometrical analysis of the structure has been done. The filtenna with band stop element has been proposed for the ultra-wideband (UWB) and x-band. And simulation result is discussed. In second part of proposed model for cognitive radio application, under these introductions, geometry of the filter and antenna using bandpass character is introduced and result is discussed.

# Chapter 5

# Conclusion and Future Work

This thesis describes the introduction to finite difference method and the reconfigurable Filtenna and its applications. The brief introduction to computational electromagnetics are studied. The analysis of the Maxwell equation and microstrip antenna parameter using finite difference method studied. The characteristic impedance of microstrip line is calculated using the finite difference method. In future the radiation pattern and directivity of the antenna can be calculated using FDM. Two filtenna are proposed, one is for UWB and X-band application and another cognitive radio application. In first design using band-rejection characteristics of the open stub that is integrated to the monopole antenna is proposed. Using this if we applied the open stub than the UWB band is rejected and only x band is passes. In future open stub of the filtenna can be controlled by the reconfigurable switch like p-i-n diode etc. Second proposed filtenna is for the cognitive radio application. In this filtenna the band pass filter characteristics are used. We achieve the bandpass characteristics form mutual coupling of the strips and the frequency tuning can be done by the varactor diode. As the varactor diode characteristics is changed frequency shifting is done. The incorporation of the tunable filter into the wideband antenna feeding network constitutes the proposed tunable filtenna. A narrowband frequency tuning is achieved for the proposed filtenna without affecting its omni-directional radiation characteristic.

New techniques such as graph model, neural networks can be used to optimize the filtenna parameters and design procedure. Smart materials can be used for reconfigurabilty as it can decrease the size of the filtenna. Hybrid filtenna such as frequency with pattern reconfigurabilty for multiband and added interference rejection can also be designed for better functionality.

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