DESIGN AND ANALYSIS OF FREQUENCY RECONFIGURABLE DIELECTRIC RESONATOR ANTENNAS

A Thesis submitted in partial fulfillment of the Requirements for the degree of

Master of Technology
In
Electronics and communication Engineering
Specialization: Communication and Networks

By
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May 2015

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Under the Guidance of
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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

ROURKELA- 769008, ODISHA, INDIA

This is to certify that the work in this thesis entitled DESIGN AND ANALYSIS OF FREQUENCY RECONFIGURABLE DIELECTRIC RESONATOR ANTENNAS by Jayaprakash Das is a record of an original research work carried out by his during 2014-2015 under my supervision and guidance in partial fulfilment of the requirement for the award of the degree of Master of Technology in Electronics and Communication Engineering (Communication and Networks), National Institute of Technology, Rourkela. Neither this thesis nor any part of it, to the best of my knowledge, has been submitted for any degree or diploma elsewhere.

Place: NIT Rourkela

Date: 19 May 2015

Dr. Santanu Kumar Behera

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ROURKELA- 769008, ODISHA, INDIA

Declaration

I certify that

a) The work comprised in the thesis is original and is done by myself under the supervision of my supervisor.

b) The work has not been submitted to any other institute for any degree or diploma.

c) I have followed the guidelines provided by the Institute in writing the thesis.

d) Whenever I have used materials (data, theoretical analysis, and text) from other sources, I have given due credit to them in the text of the thesis and giving their details in the references.

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Jayaprakash Das
19 May 2015

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Jayaprakash Das

ABSTRACT

In this thesis different types of frequency reconfigurable dielectric resonator antennas are designed for various wireless communication applications. Wireless communications now a days are becoming a piece of everyday existence of individuals. Thus to attain efficient and reasonable communication, conservative and proficient radiators are needed. Surely, one of the productive radiators is Dielectric resonator antenna (DRA). The reconfiguration capacity maximizes the antenna performance in a changing scenario. Frequency reconfiguration can be achieved by switching parts of the antenna “ON” or “OFF”. Different switches such as pin diodes, varactor diodes, MEMS switches etc. are used for this purpose.

In this thesis, first a simple dielectric resonator antenna with microstrip strips on two edges of the dielectric resonator is designed. The dielectric constant of the DR is taken as ε_r = 10 with dimensions 13mm× 13mm × 10mm. The DR is placed on a ground plane of dimensions 100 mm × 150 mm and substrate of ε_r = 3.38. By using shorting tabs on one edge of the DRA, six different operating conditions are obtained.

Second, a H shaped frequency reconfigurable DRA using coplanar waveguide (CPW) feed is presented. This antenna consists of two dielectric resonators of dielectric constant 15 each. The DRs are placed on a substrate of dielectric constant 3.2. CPW feeding technique is used to excite the DRA. Two PIN diodes are used on the line connecting the dielectric resonators. Using these PIN diodes 3 operating modes, such as OFF ON, ON OFF and ON ON are obtained. In OFF ON state 2 bands with center frequencies 2.7 GHz for WLAN application and 4.8 GHz for INSAT (Indian national satellite system) application are obtained. In ON OFF state a single narrow band with center frequency 3.7 GHz is obtained for WLAN and international mobile telecommunications (IMT) applications. Similarly in ON ON state a dual band with frequencies 2.6917 and 5.2589 is obtained for WLAN applications.

Finally, an aperture coupled dielectric resonator antenna with power divider is designed. First of all the antenna is analyzed without any PIN diodes and later the frequency reconfigurability is obtained by using PIN diodes in the feed network. In the first case a single band with center frequency 2.9 GHz is obtained for WLAN applications. Later by using switching elements 3 different operating frequencies are obtained.

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Chapter 1

Thesis Overview

1.1 Introduction

Wireless communications now a days are becoming a piece of everyday existence of individuals. Thus to attain efficient and reasonable communication, conservative and proficient radiators are needed. Surely, one of the productive radiators is Dielectric resonator antenna (DRA). An antenna can be defined as a metallic device, such as a rod or a wire that can be used for radiating or receiving radio waves. In other words it can be defined as a means for radiating or receiving radio waves. The field of wireless communication has been undergoing a revolutionary growth in last decade such as 2G wireless communication (portable mobile phones), 3G, Bluetooth, wireless LAN (WLAN) etc. The most important component of any wireless communication is antenna. Mainly two types of antennas are used in the last two decades. One is microstrip patch antenna and another is Dielectric resonator antenna. A dielectric resonator antenna can be defined as an antenna that makes use of dielectric materials which can be used at higher frequencies because of their less conduction loss property. It is made of a ceramic material that comes in various shapes and is placed on a ground plane which is mainly metal. Since the requirement of frequency range has been increased and now a days antennas that operate in millimetre wave frequencies and microwave frequencies are needed, the conduction losses in metallic antennas increase with increase in frequency. DRA has many advantages over microstrip antennas. DRA lacks any metal parts, which provides the advantage of operating at higher frequency without any conduction losses. Therefore by taking a dielectric material which has very low loss, the radiation efficiency can be improved at very high frequencies, since there is no surface waves and conductor losses within the DRA. DRA is monetarily reasonable and it is having alluring highlights like - simple configuration, easy design, and simple fabrication methods. It also provides flexibility in analysing the result so that the required resonant frequency can be achieved depending upon our coverage requirements.

1.2 Frequency reconfigurable antennas

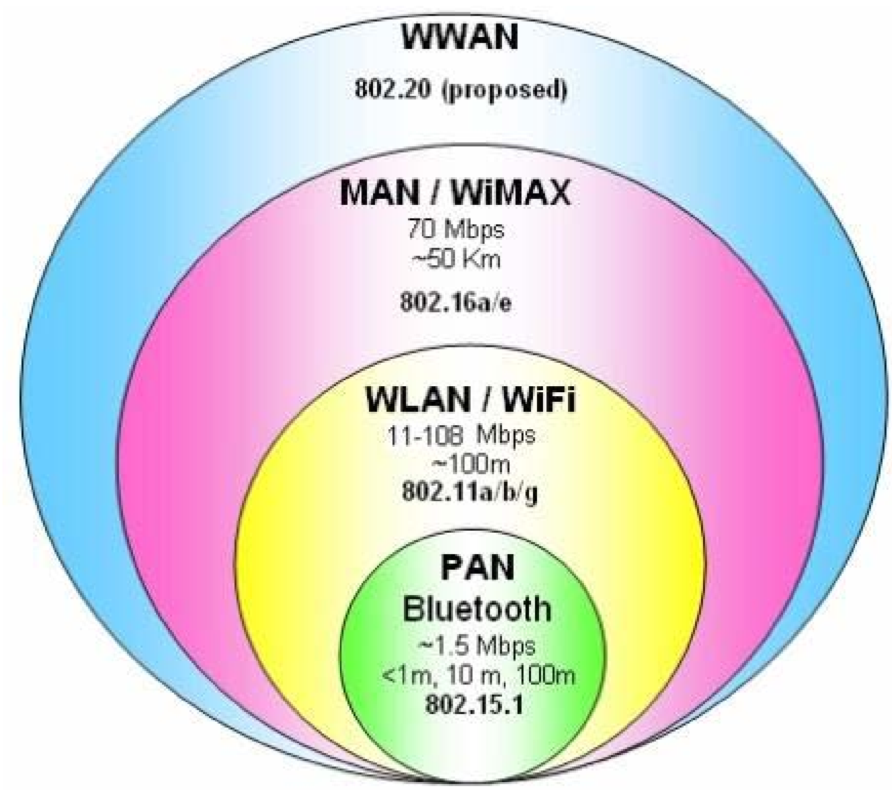
Now a days a great effort has been done on reconfigurable antennas. A reconfigurable antenna can be defined as an antenna which is capable of dynamically change its frequency of operation and radiation pattern in a suitable manner. This reconfiguration capacity maximizes the antenna performance in a changing scenario. Frequency reconfigurable antennas have capability of dynamically changing their frequencies as per requirement. Frequency reconfiguration can be achieved by changing physically or electrically the dimensions of the antenna i.e. by altering the current flow in the antenna. Also reconfigurable antennas can be used to obtain wide bandwidth antennas. This can be achieved by switching parts of the antenna "ON" or "OFF". Different switches such as pin diodes, varactor diodes, MEMS switches etc. are used for this purpose.

1.3 Thesis motivation

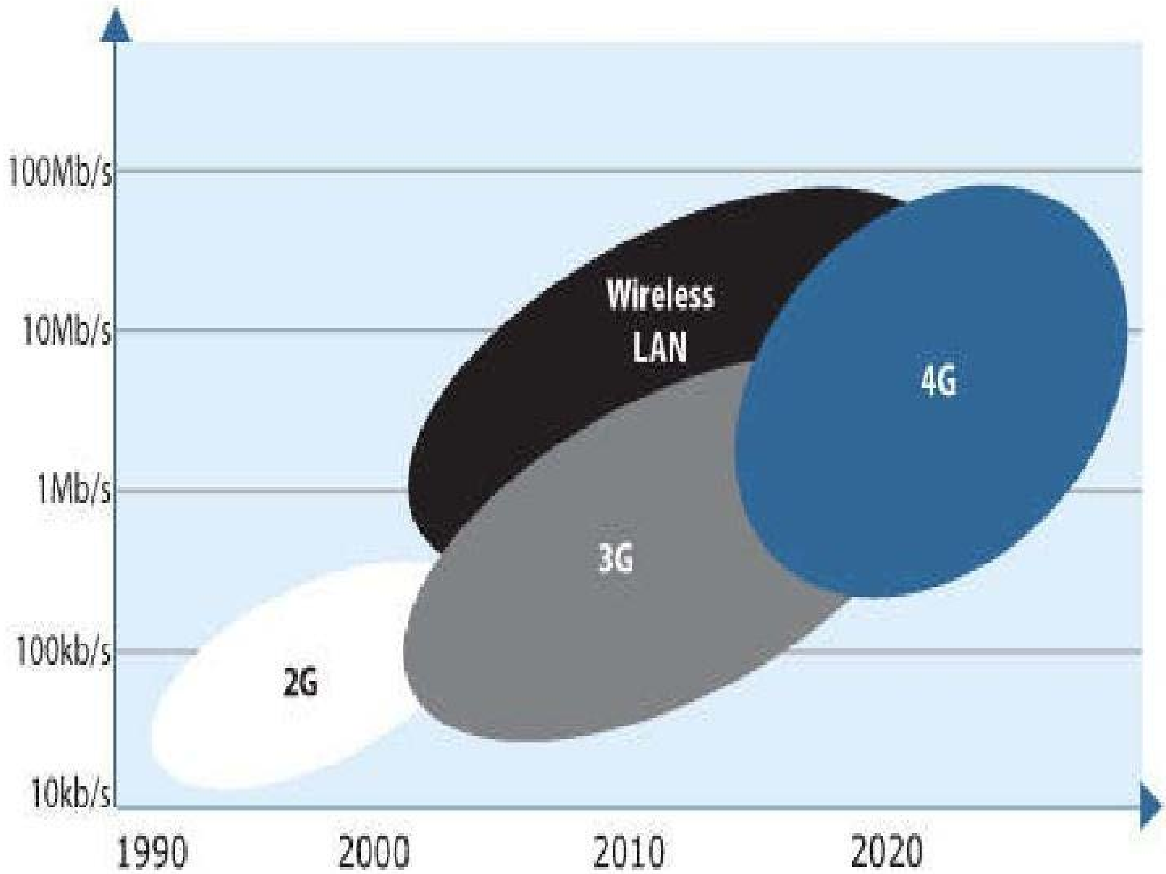
Dielectric resonator antennas have some appealing qualities which make them extremely encouraging and reasonable at microwave frequencies for wireless applications. Now a day's wireless communications are becoming part of day to day life. So to get efficient communication proficient radiators are needed. Dielectric resonator used as antenna is one of the promising radiators which provides very less conduction loss even at microwave frequencies. DRA has many appreciable features like simple design, easy fabrication method, economically affordable and it can be used for various applications. Initially microstrip patch antennas were used which mainly contain metal (cupper) as radiating element. These antennas are suitable for low frequency of operation, but as the frequency range of interest increases it becomes lossy. Since with increase in frequency conduction losses and surface waves also increase which affect efficient operation of the antenna. To avoid all these dielectric materials are used as radiating elements. The size of the DRA is proportional to $\lambda_0/\sqrt{\varepsilon_r}$, where λ_0 is free space wavelength and ε_r is dielectric constant of the material. So by choosing a material of high dielectric constant the size of the antenna can be minimized.

DRA has the advantages of high flexibility and versatility, so that the designs made with it can support a wide range of physical or electrical requirements for various communication applications. It makes DRA as the best option for today's communication and other wireless applications. Also we can choose various shapes of the DRA like hemispherical, cylindrical, rectangular etc.

To adapt with any changing scenario antennas with reconfigurable properties are needed. By using a reconfigurable antenna the use of more than one antenna can be avoided. Because a single reconfigurable antenna can be used for multiple applications. Reconfigurable antennas are divided in to three categories, i.e. frequency reconfigurable antennas, pattern reconfigurable antennas, polarization reconfigurable antennas. In this thesis we will find design and analysis of frequency reconfigurable antennas used for various communication applications like WLAN, WIMAX and IMTS etc. Frequency reconfigurable antennas operate in more than one resonating frequency which can be obtained by switching certain parts of the antenna or by altering the current flow to the antenna. Different switches like pin diode, varactor diode, MEMS are used for this purpose. Pin diodes have advantage like good isolation, low loss inexpensive and they are easy to achieve. They also have high tuning speed and low parasitic reactance and they are small in size. In this thesis we will find design of different frequency reconfigurable DRAs and analysis for optimizing the antenna parameters through parametric studies.



(a)



(b)

Figure 1.1 Different wireless technologies classified according to their speed

1.4 Literature review

Initially for many years dielectric resonators have been used in microwave circuit applications like oscillators and filters. In 1939 Richtinger was the first one to theoretically demonstrate dielectric resonators. He observed them as dielectric spheres and toroids and their modes were first analysed by Okaya and Barash in 1960. The development of these materials showed that dielectric resonators can be used as high Q and low loss elements in microwave circuit applications such as oscillators and filters. In the early 1980s three basic shapes of the dielectric resonator i.e. cylindrical, hemispherical, rectangular are examined are examined to see its result as an antenna. In early 1990s various feeding mechanism were proposed to excite the DRAs and by the mid-1990s linear and planar DRAs are employed for various applications.

The main objective of this thesis is to obtain frequency reconfigurability by using pin diodes as switching elements. To achieve this various geometries such as single element frequency reconfigurable DRA [1], frequency tunable differentially fed DRA [2], frequency tuning using multiple parasitic strips [5] etc. are proposed. In the 1st design [1] proposed by S. Danesh, S.K.A. Rahim and et-al in the year 2013 a single DRA is considered in which CPW feeding method is used. The DRA is fed from both the sides and pin diodes are placed on the line connecting to the DRA. Two pin diodes are used by which three operating states are obtained i.e. ON ON , ON OFF and OFF ON. In the ON OFF and OFF ON state two narrow bands at frequencies 3.7GHz and 6.1GHz are obtained. But in ON ON state a wide band with 65% impedance bandwidth is obtained. This antenna can be used for IMT systems and WLAN applications. But this antenna does not provide any appreciable frequency in OFF OFF state. In another design [2] proposed by C.X. Hao, B. Li and et-al in the year 2011 two varactor diodes are used on two sides of the DRA to obtain different frequency of operation. It is achieved by changing the capacitance of the varactor diodes. Similarly in 2005 K. K. So and K.W. Leung proposed an antenna in which parasitic slot is used to obtain frequency tuning [5]. The parasitic strip is made in the ground plane and by changing its length, different resonant frequencies are obtained. Similarly multiple strip [6] can be used to obtain frequency reconfiguarability. Another way to obtain more than one resonant frequency is by keeping air gap in between the DRA and the ground plane [7]. Two metalized dielectric slogs are inserted in between the DRA and the ground plane so that the coupling capacitance can be changed. In this thesis pin diodes are used for switching purpose. For ON state the pin diodes are in forward bias and in OFF state they are reverse biased [8]. In 2008 D. A. McNamara, A. Petosa, S. Thirakoune and J. Desjardins suggested electronically frequency reconfigurable dielectric resonator antennas [9]. Different feeding methods like probe, aperture coupling, CPW feed, microstrip line feeding can be used to excite the DRA. In 2006 A.A. Kishk and Kai Fong Lee observed different feeding techniques that can be used to excite the DRA [3]. They analysed several dual polarized DRA excitation techniques by taking a simple cylindrical disk DRA designed to resonate at 10 GHz. S. Danesh, M. Abedian, S. K. A. Rahim and M.R. Hamid [4] in 2015 proposed a compact frequency reconfigurable DRA for WLAN and LTE/WWAN applications [4]. They considered 4 dielectric resonators with permittivity of 10 each and three pin diodes that are located in the feed line connecting two dielectric resonators.

1.5 Thesis outline

The outline of the thesis is as follows.

Chapter 2: In this chapter the basic theory behind DRA, its characteristics, advantages and disadvantages are presented. Different shapes of DRA like hemispherical, cylindrical, rectangular etc. are also presented in this chapter. This chapter presents different coupling techniques or feeding methods used to excite the DRA. The feeding techniques include slot aperture, coaxial feed, microstrip line feed, coplanar coupling, dielectric image guide coupling etc. The advantages and disadvantages of the DRA are also explained in this chapter.

Chapter 3: In this chapter a brief theory about reconfigurable antennas and different switching techniques, their advantages are presented. The use of these switching techniques in different antennas are explained.

Chapter 4: In this chapter some basic theory on frequency reconfigurability is presented. One frequency reconfigurable DRA is designed using ideal switches. All the parameters are optimized and the simulated results are presented.

Chapter 5: Different frequency reconfigurable DRAs, designed using switching elements like pin diodes are described. Designs are simulated using CST microwave studio suite 2012. The simulated results are described in terms of different antenna parameters such as return loss, radiation pattern, gain, VSWR etc. The parametric studies are done to obtain optimum results and all the simulation results are presented.

Chapter 6: This chapter describes conclusion and the future work. After this publication and references are presented.

Chapter 2

Dielectric resonator antenna

2.1 Introduction to DRA

A dielectric resonator antenna can be defined as a radio antenna frequently used at microwave frequencies and higher. It is made of a block of ceramic material with different shapes, called dielectric resonators, placed on a metal surface called ground plane.

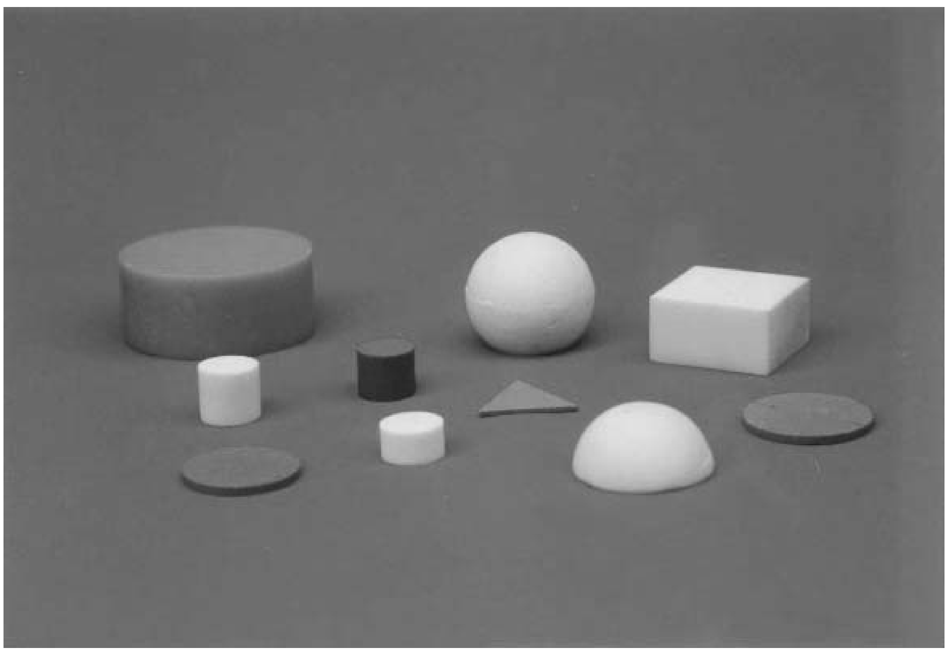


Figure 2.1 Different shapes of the DRA

Over the last decades two class of antennas, i.e., microstrip antennas and dielectric resonator antennas have been widely used. Since microstrip antennas have high quality factor, they possess very narrow bandwidth. If the thickness of the substrate is increased then the bandwidth will increase, but the surface wave and ohmic loss will also increase. This reduces the radiation efficiency. Also with increase in frequency conduction losses in metallic antennas increase thereby affecting the overall performance of the antenna. Compared to microstrip antenna dielectric resonator antenna has wider impedance bandwidth, less size, conduction loss is less because of the absence of metallic parts. So the radiation efficiency can be improved by properly choosing a dielectric material with low loss and optimum characteristics.

2.2 Characteristics of the DRA

- The size of the DRA is inversely proportional to the dielectric constant by $\frac{\lambda_0}{\sqrt{\varepsilon_r}}$, where λ_0 is free space wavelength and ε_r is the dielectric constant of the material. So by choosing a material of high dielectric constant size of the antenna can be reduced.
- By changing the aspect ratio, the resonant frequency and the Q-factor can be changed for a fixed dielectric constant which adds more design flexibility.
- The radiation efficiency can be improved by taking a dielectric material with less conductor losses even at millimeter wave frequencies.
- As size is inversely proportional to dielectric constant, so by taking a high dielectric constant the size of the DRA can be reduced. Various DRs with dielectric constants starting from 8 to 100 are available which makes the designer to have control over dimension of the DRA.
- DRAs can operate over a long range of frequencies starting from 1.3GHz to 40GHz.
- Several feeding techniques as discussed earlier can be used to excite the DRA. These feeding techniques are microstrip line feeding, coaxial probe, CPW feed, aperture coupling feeding etc.
- DRA supports different modes such as TE, TM etc. The radiation patterns of these modes are similar to short electric or magnetic dipoles. We can choose different modes as per our requirement.
- DRAs have very high quality factor upto 10000 (f = 10GHz).
- The flexibility and versatility of DRA makes them suitable for various wireless communication applications.
- DRAs have a wide range of temperature coefficient of resonance frequency.

2.3 Limitations of DRA

- Fabrication complexity is more.
- Drilling of the ceramic material (dielectric resonator) is required in some feeding methods (probe).
- Fabrication cost is more especially for array application.
- It is very difficult to get the material of desired dielectric constant (i.e. more than 10).

2.4 Different shapes of the Dielectric resonator antennas

There are 3 basic shapes of the DRA.

- Hemispherical DRA
- Cylindrical DRA
- Rectangular DRA

2.4.1 Hemispherical DRA

Hemispherical DRA is one of the most basic shape and since it has exact analytical solution exist to describe different characteristics it is studied primarily. But its fabrication is very difficult and it has only one degree of freedom i.e. the radius of the hemisphere is used to determine the antenna performance i.e. resonant frequency and quality factor. So the designer has no control over the antenna size or its bandwidth.

The geomatry of the hemispherical DRA is shown in the figure below. The dielectric constant of the DRA is ε_r and the radius of the sphere is a.

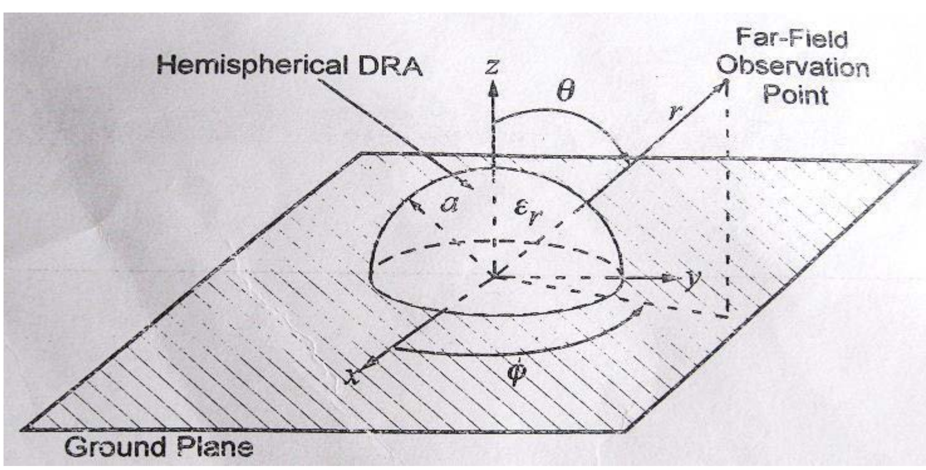


Figure 2.2 Hemispherical DRA

From the figure it is shown that the DRA is mounted on a ground plane, which is assumed to have infinite conductivity and length. Two types of modes can be present in the hemispherical DRA i.e. transverse electric (TE) and transverse magnetic (TM). For transverse electric the radial component of electric field is zero ($E_r = 0$) and for transverse magnetic the radial component of the magnetic field is zero ($H_r = 0$).

2.4.1.1 The TE_{111} mode

It is the lowest order mode of the hemispherical DRA. The frequency of operation and quality factor of the hemispherical DRA is obtained by solving the following equation:

$$\frac{J_{\frac{1}{2}}\left(\sqrt{\varepsilon_r}k_0a\right)}{J_{\frac{3}{2}}\left(\sqrt{\varepsilon_r}k_0a\right)} = \frac{H_{\frac{1}{2}}^{(2)}(k_0a)}{\sqrt{\varepsilon_r}H_{\frac{1}{2}}^{(2)}(k_0a)} \tag{2.1}$$

Where $J(x)$ is the first order Bessel function, $H^2(x)$ is the second order Hankel function, and k_0 is the free space wave number. After obtaining k_0 the resonant frequency is determined by using:

$$f_{GHz} = \frac{4.7713 \ \mathrm{Re}(k_0a)}{a_{cm}} \tag{2.2}$$

Where the resonant frequency is expressed in GHz, and the radius is in cm. The radiation Q-factor is given by

$$\mathrm{Q} = \frac{Re\ (k_0a)}{2\ Im(k_0a)}, \quad \mathrm{BW} = \frac{\Delta f}{f_0} = \frac{s-1}{\sqrt{s}Q} \tag{2.3}$$

2.4.1.2 The TM_{101} mode

The hemispherical DRA radiates like a short electric monopole antenna in this mode. The resonant frequency and radiation quality factor can be calculated from the following equation:

$$\frac{1}{\sqrt{\varepsilon_r}k_oa} - \frac{J_{1/2}\left(\sqrt{\varepsilon_r}k_0a\right)}{J_{3/2}\left(\sqrt{\varepsilon_r}k_0a\right)} = \frac{\sqrt{\varepsilon_r}}{k_0a} - \sqrt{\varepsilon_r}\frac{H_{1/2}^{(2)}(k_0a)}{H_{3/2}^{(2)}(k_0a)} \tag{2.4}$$

Using k_0 the following equations are used to calculate resonant frequency and Q-factor.

$$f_{GHz} = \frac{4.7713 \ \mathrm{Re}(k_0a)}{a_{cm}} \tag{2.5}$$

$$\mathrm{Q} = \frac{Re\ (k_0a)}{2\ Im(k_0a)} \tag{2.6}$$

2.4.2 The Cylindrical DRA

Cylindrical DRAs have very high Q-factor and compact size. They are mostly used in filters, oscillators and microstrip technologies. The cylindrical DRA has height h, radius a, dielectric constant ε_r, as shown in the figure below.

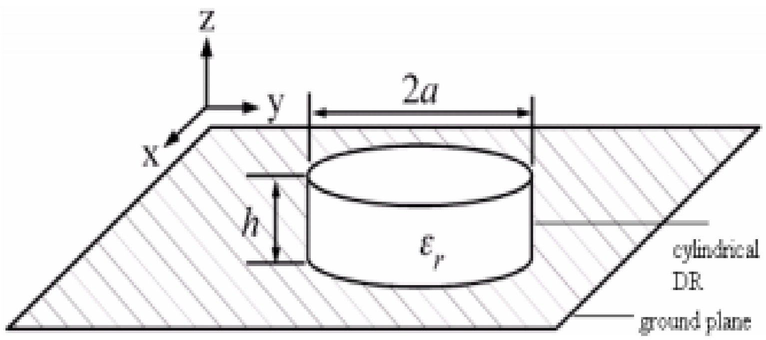


Figure 2.3 Cylindrical DRA

The cylindrical DRA offers more design flexibility than hemispherical DRA, because it has 2 degrees of freedom i.e. a/h by changing which the quality factor and resonant frequency can be changed. In hemispherical DRA, for a given radius and dielectric constant, it has only one resonant frequency and one quality factor. But in cylindrical DRA we can change both the radius and height to get different resonant frequencies and quality factors for a given dielectric constant.

So with a cylindrical DRA the most suitable aspect ratio can be chosen to obtain the desired frequency and bandwidth. Like hemispherical DRA it also supports TE mode and TM mode.

2.4.2.1 $TE_{01\delta}$ mode

Unlike hemispherical DRA, there is no exact solution to the fields of a cylindrical DRA. The equations used to calculated the resonant frequency and quality factor are given below.

$$k_0 a = \frac{2.327}{\sqrt{\varepsilon_r + 1}} \left\{ 1 + 0.2123 \frac{a}{h} - 0.00898 \left(\frac{a}{h} \right)^2 \right\} \tag{2.7}$$

After finding $k_0 a$ the following equation can be used to calculate the resonant frequency:

$$f_{GHz} = \frac{4.7713 \ \mathrm{Re}(k_0 a)}{a_{cm}} \tag{2.8}$$

$$Q = 0.078192\varepsilon^{1.27}\left\{1+17.31\left(\frac{h}{a}\right)-21.57\left(\frac{h}{a}\right)^2+10.86\left(\frac{h}{a}\right)^3-1.98\left(\frac{h}{a}\right)^4\right\} \tag{2.9}$$

2.4.2.2 $TM_{01\delta}$ mode

The resonant frequency can be calculated by calculating the value of $k_0 a$.

$$k_0 a = \frac{\sqrt{3.83^2+\left(\frac{\Pi a}{2h}\right)^2}}{\sqrt{\varepsilon_r+2}} \tag{2.10}$$

Quality factor is given by

$$Q = 0.008721\varepsilon_r^{0.888413}e^{0.0397475\varepsilon_r}\left\{1-\left(0.3-0.2\frac{a}{h}\right)\left(\frac{38-\varepsilon_r}{28}\right)\right\}\mathrm{X}\left\{9.498186\frac{a}{h}+2058.33\left(\frac{a}{h}\right)^{4.322261}e^{-3.50099\left(\frac{a}{h}\right)}\right\}$$

In simpler form quality factor is calculated from (2.11)

$$\mathrm{BW} = \frac{\Delta f}{f_0} = \frac{s-1}{\sqrt{s}Q} \tag{2.12}$$

Where s is the voltage standing wave ratio.

f_0 is the resonant frequency.

Δf is the absolute bandwidth.

2.4.3 The rectangular DRA

The rectangular DRA is one of the most widely used DRA. It offers the greatest design flexibility among the three basic shapes.

It is characterized by a width w , a depth d , and a height h . The rectangular DRA has advantage of having two degrees of freedom (length,width and depth). By varying several aspect ratios the antenna can be chosen to all resonate at the same frequency, while giving different Q-factors at a fixed dielectric constant.

The ratios w/h or w/d can be chosen independently to get different operating conditions.

The modes in a rectangular DRA are classified as TE mode and TM mode, but with the DRA mounted on the ground plane mainly TE modes are excited.

The rectangular DRA with dielectric constant ε_r is shown in the figure below. The DRA can support TE^x, TE^y or TE^z modes. If $w > d > b$, then $f_x > f_y > f_z$,so by properly taking the dimensions the unwanted modes can be avoided.

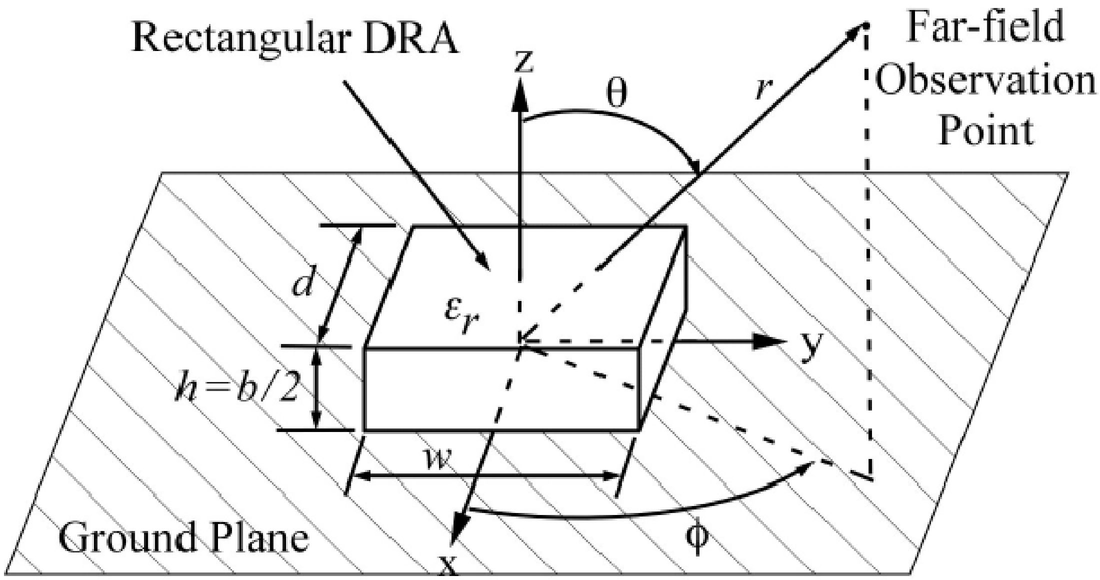


Figure 2.4 Rectangular DRA

The resonant frequency, f_0 , can be found from the equation below.

$$f_{GHz} = \frac{15F}{w_{cm}\pi\sqrt{\varepsilon_r}} \tag{2.13}$$

Where

$$k_0 = \frac{2\pi}{\lambda_0} = \frac{2\pi f_0}{c} , k_y = \frac{\pi}{w} , k_z = \frac{\pi}{b} , \text{and } k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \tag{2.14}$$

k_0 is wave number.

The resonant frequency can be calculated from the normalized frequency F.

$$F = \frac{2\pi w f_0\sqrt{\varepsilon_r}}{c} \tag{2.15}$$

Where f_0 is the resonant frequency and c is the velocity of light.

The above equation can also be written as

$$f_{GHz} = \frac{15F}{w_{cm}\pi\sqrt{\varepsilon_r}} \tag{2.16}$$

The radiation Q-factor of the rectangular DRA is given by

$$Q = \frac{2\omega W_e}{P_{rad}} \tag{2.17}$$

The normalized quality factor can be calculated as

$$Q_e = \frac{Q}{\varepsilon_r^{\frac{3}{2}}} \quad (2.18)$$

Design procedure:

Step 1. Determine the quality factor using the following equation.

$$\text{BW} = \frac{\Delta f}{f_0} = \frac{s-1}{\sqrt{s}Q} \quad (2.19)$$

Step 2. Determine the dielectric constant. To obtain suitable values of ε_r the quality factor is converted to Q_e and Q_e is calculated for different values of dielectric constants among which the best value is selected.

Step 3. Determine F using the formula below in terms of w (cm) and calculate its value for different value of w.

$$F = \frac{2\pi w f_0 \sqrt{\varepsilon_r}}{c} \quad (2.20)$$

Step 4. Finally the DRA dimensions (w, b, d) are determined by using the graph between F vs. d/b .Depending on the requirement the best dimension is chosen for the antenna.

2.5 Feeding techniques used to excite the DRA

There are several technique used to excite the DRA. The input impedance and radiation characteristics of the antenna are affected by the feedline. So choosing feedline is an important task. It also determines which mode is excited in the DRA. The power must be coupled perfectly with the antenna when choosing feeding methods. There are mainly 5 types of feeding techniques used to excite the DRA.

2.5.1 Aperture coupling

This is one of the common method in which the DRA is excited through an aperture made on the ground plane over which it is placed. The most probably used aperture is the small rectangular slot cut from the ground plane. In aperture coupling since the feed network is placed below the ground plane, the radiating aperture is isolated from any unwanted spurious radiation. The aperture is generally placed at the center position below to the DRA, where magnetic field is maximum, to achieve strong coupling.

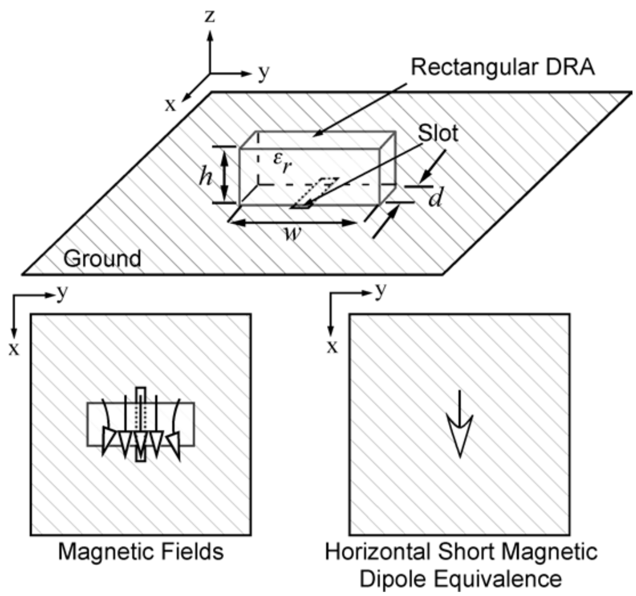


Figure 2.5 Aperture coupling to the DRA

The slot length l_s and width w_s is calculated from the following formulas.

$$l_s = \frac{0.4\lambda_0}{\sqrt{\varepsilon_e}} \text{ , where } \lambda_0 \text{ is the free space wavelength and} \tag{2.21}$$

$$\varepsilon_e = \frac{\varepsilon_r + \varepsilon_s}{2} \tag{2.22}$$

ε_r and ε_s are the dielectric constants of the DRA and the substrate.

$$w_s = 0.2\ l_s \tag{2.24}$$

The length of the slot is chosen large to allow sufficient coupling between the DRA and the feed line, whereas the width of the slot is chosen very narrow to avoid any backlobe component.

To cancel the reactance of the slot aperture the stub extension s is calculated by using the formula:

$$s = \frac{\lambda_g}{4} \tag{2.25}$$

2.5.2 Probe coupling

Another common method to excite the DRA is probe feeding. The probe is normally a coaxial cable in which the center pin is extended to the DRA through the ground plane. To have strong coupling the probe must be placed at a position where the electric field is maximum. The probe can be placed adjacent to the DRA or through the DRA. The coupling can be optimized by varying the height of the probe or the location of DRA. The probe can be used in any type of DRA. The height of the probe is selected to be less than that of DRA to avoid probe radiation.

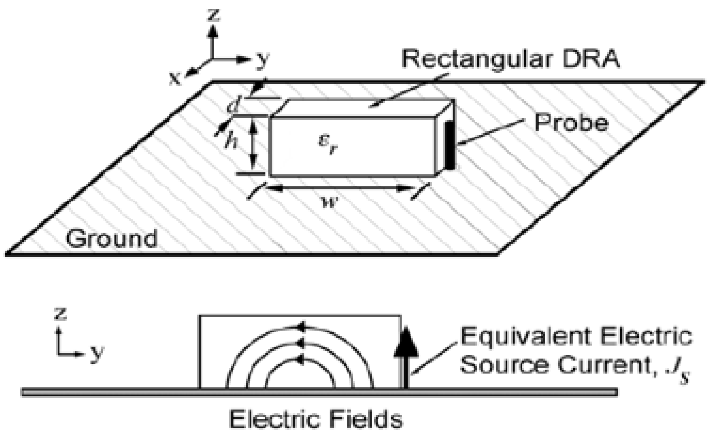


Figure 2.6 Probe feeding to DRA

2.5.3 Microstrip line coupling

In this type of coupling method a microstrip line is added to the side of the DRA to excite it. In rectangular DRA microstrip coupling can be used to excite the $TE_{\delta 11}$ mode and in cylindrical DRA it is used to excite the $HE_{11\delta}$. The amount of coupling can be controlled by chnging the distance s between the DRA and the microstrip line.

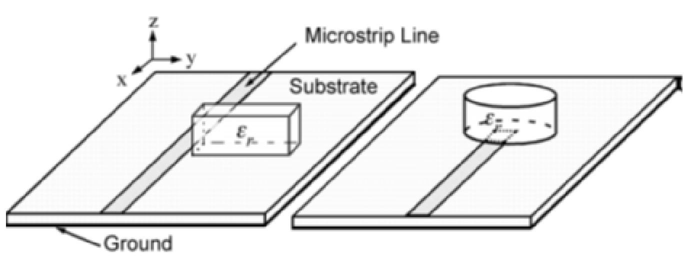


Figure 2.7 Microstrip line coupling

2.5.4 Coplanar coupling

This is another method of coupling to the DRA in which open circuit coplanar waveguides can be directly fed to the DRA. The impedance can be matched by adding extra stubs or loops at the end of the line and the coupling can be controlled by adjusting the position of the DRA over the loop. To ensure proper coupling the dimension should be chosen large enough to avoid the interference.

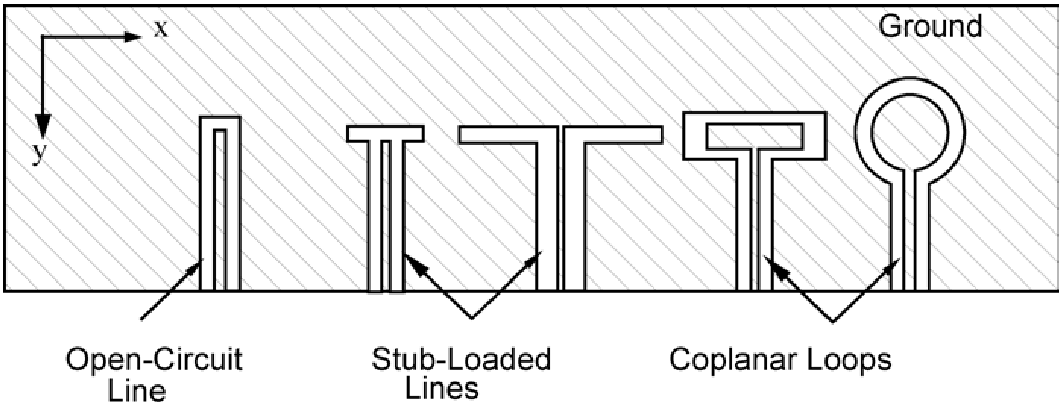


Figure 2.8 Various coplanar feeds for coupling to DRAs

2.5.5 Dielectric image guide coupling

In this type of feeding method dielectrics are used to provide coupling to the DRA. It has advantage over microstrip coupling is that it has very less conduction loss at millimeter-wave frequencies. Here the amount of coupling to the DRA is very small. It is mainly used to feed an array of DRAs.

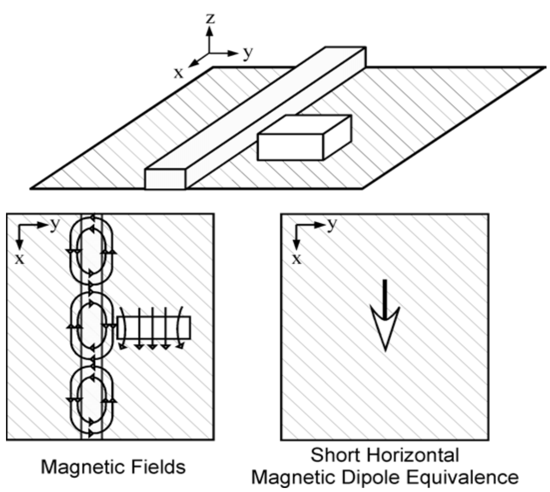


Figure 2.9 Dielectric image guide feed for DRAs

Chapter 3

Reconfigurable Dielectric resonator antenna

3.1 Introduction

With the constantly expanding requests of the modern wireless communication the improvement of the mobile devices and applications are necessary. As antenna is one of the crucial component of any wireless communication, its design advancement is also necessary. To fulfill the demands of different communication industry the antenna should be versatile or increasingly adaptable because of different constraints such as antenna size, radiation pattern, bandwidth, polarization, antenna geomatry, operating frequency etc. Therefore the designers are forced to examine reconfiguarable antennas, which can adapt the required changes needed for the antennas to operate in optimum condition. This antennas will be very useful if cognitive radio or software defined radio is to be realized. The literal meaning of configure is to arrange or compose the parts of something for a desired cause. For example, configuring an antenna means determining the shape, size, substrate parameters, feed location etc. for the antenna so that it will radiate at the desired frequency and polarization. If because of some external or internal effect the required frequency or polarization changes, then the antenna must be reconfigured to satisfy the new operating conditions.

The reconfigurable antenna can be defined as an antenna that is capable of modifying its characteristics such as frequency, pattern, polarization in a controlled and reversible manner. This property of the reconfigurable antenna makes the antenna performance optimum in a changing scenario.

The basic characteristics of the antenna that can be reconfigured are frequency, radiation pattern, polarization, impedance bandwidth. The reconfigurable antennas change their performances by changing the flow of current in that anteena. This can be achieved by using mechanically movable parts, attenuators, different types of switches etc. Complex system requirements can be fulfilled by using reconfigurable DRAs that can operate perfectly in changing scenarios

3.2 Different types of antenna reconfiguration

Reconfigurable antennas can be classified according to three fundamental paraneters.

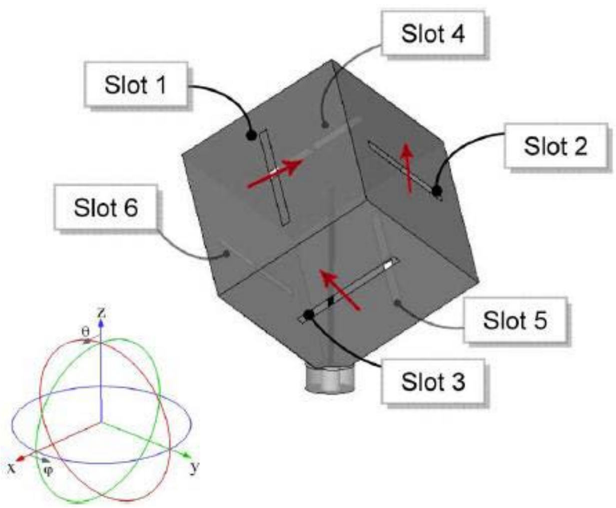
- Antenna radiation pattern
- Antenna polarization
- Frequency of operation

3.2.1 Radiation pattern reconfigurability

As the name suggests an antenna can be made pattern reconfigurable by changing the radiation pattern characteristics. So it is mainly based on the intentional modification of the spherical distribution of radiation pattern. Beam steering is one of the most important application of pattern reconfigurability and it is capable of changing the direction of maximum radiation to maximize the gain. Pattern reconfigurable antennas are mainly designed using rotatable or movable structures or using different types of switches. In applications like cognitive radio the use of pattern reconfigurable antennas would be invaluable as the antenna pattern can be modified to maximize the efficiency and conserve battery life. As we know radiation pattern mainly depends on the arrangement of current on the antenna surface, so to obtain reconfigurability it should be rearranged while keeping in mind that the frequency and polarization should not be altered. So it is quite challenging method [9] . However, now a days different techniques have employed to obtain pattern reconfigurability without changing the frequency of operation or polarization [10] [11]. Such a technique is to include a hybrid high impedance surface with multiple feeds to obtain a beam steerable loop capable of steering in to four quadrants [10].

Sarrazin presented another design in which he used a single feed to excite a metallic cavity which radiates through rectangular slots as shown in the figure below [11]. The pattern of the antenna is changed by using PIN diodes at the center of the slots.

Another design proposed by Bai and Xiao in which they designed a patch top loaded monopole antenna where the radiation pattern is analyzed with two couples of magnetic dipoles [12]. They used varactor diodes to adjust the phase of the dipoles and the pattern is reconfigured in two orthogonal planes (shown in fig 4.2). In addition to above techniques many other methods exist most of them make use of symmetry in the feeding mechanism so that the frequency response can be maintained.



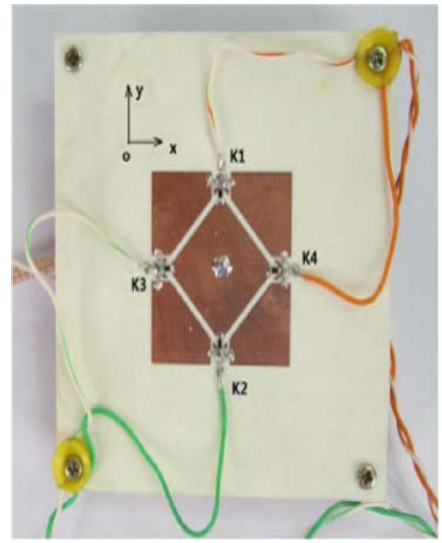


Figure 3.1(a)pattern reconfigurable cubic antenna [11]   (b) Two element dipole array [12]

3.2.2 Polarization reconfigurable antennas

This technique enables the antenna to be capable of altering or modifying its polarization modes by some means. An antenna with such capacity would give some resintance from meddling signals and give an extra level of opportunity to enhance quality as a form of exchanged antenna diversity. Since the polarization is a function of current flow on antenna surface, the methods used to adjust the polarization invole changing the feed structure or material properties or antenna structure [9]. Ferrero and et al designed an anetnna in which they varied the amplitude of the feed to the radiating patch to obtain polarization reconfigurability [13]. A quasi lumped coupler is used to feed this antenna. Two varactor diodes are used by the coupler to vary the magnitude of output between -30 dB to -15 dB. So the antenna has continuous linear polarization over a range of 90^0.

Similarly another antenna is proposed by Khaleghi et al to provide polarization reconfigurability [13]. This antenna consists of one circular patch which is placed on a thin substrate, that is supported by two non conducting lines placed on a conducting ground plane. This antenna is fed by a capacitively coupled feed that provides very good result. The two parasitic pins between the circular patch and ground plane are switched using PIN diodes to alter the polarization of the antenna. This is shown in the figure 4.3. The switching of PIN diodes enable the antenna to obtain two polarization i.e. right hand circular polarization (RHCP) and left hand circular polarization (LHCP). The radition pattern and frequency of response is not altered by this switching action.

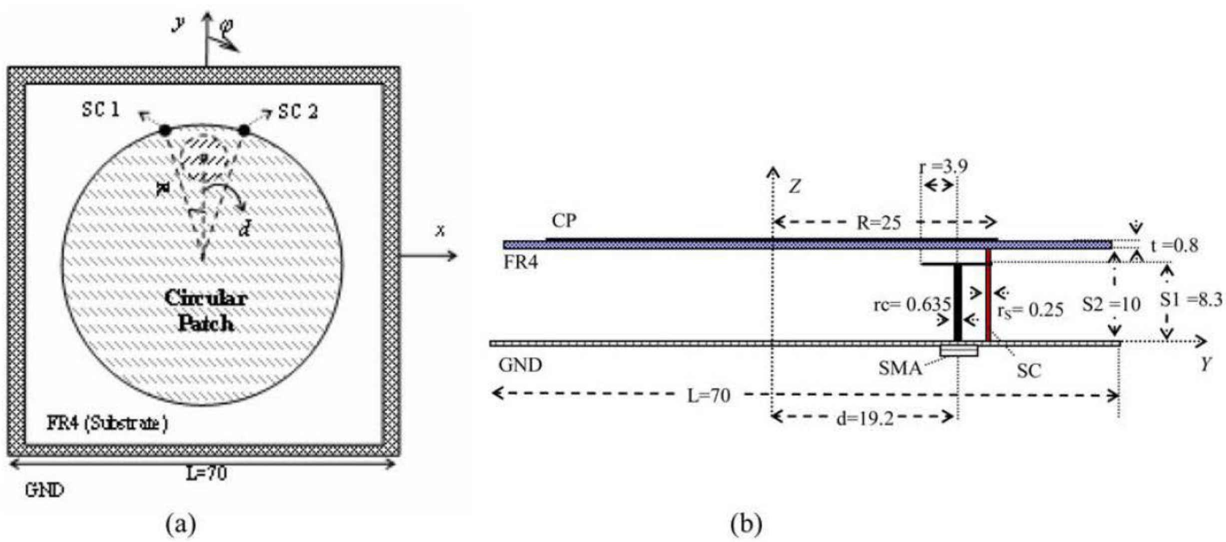


Figure 3.2 Polarization reconfigurable of circular patch antenna (a) top view (b) side view

3.2.3 Frequency reconfigurable antennas

Frequency reconfigurable antennas can dynamically change their frequency of operation as per requirement. By designing frequency agile antennas, small antennas having narrow bandwidth can be tuned to radiate over a large range of frequencies. This effectively improves the overall bandwidth performance of the antenna [15]. They are more useful in situations, where several communication systems converge, because the need of using several antennas can be replaced by using a single reconfigurable antenna. The frequency of any antenna can be altered by changing the physical or electrical dimensions, by using R.F. switches, impedance loading etc.

Frequency agile antennas capable of changing their frequency can be divided into two categories.

- Discrete tuning – Here the antenna is capable of having a finite no. of states or bands.
- Continuous tuning – Here the antenna is capable of having any no. of states or operating bands within the tuning range.

Tuning range can be expressed as

$$\text{TR} = \frac{2\left(f_{high} - f_{low}\right)}{\left(f_{high} + f_{low}\right)} \times 100\%$$

Where f_{high} and f_{low} are upper and lower frequency bounds of the operation.

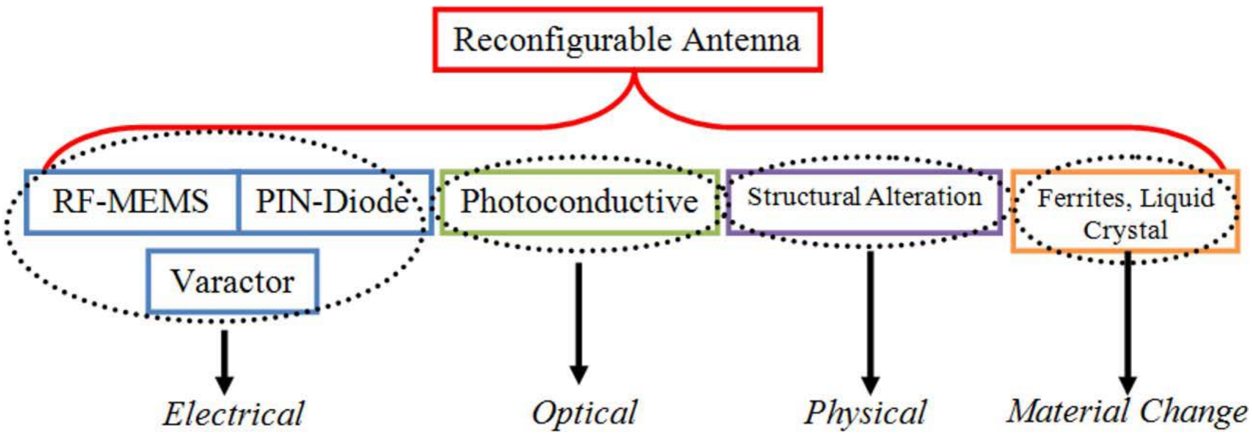


Figure 3.3 various technique used to achieve reconfigurable antennas

3.3 Different types of tuning methods to obtain frequency reconfigurability

As stated earlier there are two tuning techniques used to achieve frequency reconfigurability. One is discrete tuning and the other is continuous tuning.

3.3.1 Discrete tuning

In this type of tuning, different types of switching mechanisms are used for the antenna to be frequency reconfigurable. The most commonly used switching mechanisms are PIN diodes, microelectromechanical system (MEMS) and field effect transistors (FETs). The discretely tuned antennas have advantage over continuous tuned antennas that they can be designed for a specific band of operation. Another advantage of discretely tuned antennas is that, by switching ON or OFF, certain parts of the antennas can be made electrically absent thereby giving a large tuning range. So the switching elements are typically used to alter the flow of current at different conditions to obtain different bandwidth and frequency of operation. The switching mechanism used in discrete tuning require very small DC bias level and they have very low loss compared to continous tuning techniques in most of the cases.

There are basically three types of switching in discrete tuning method.

- MEMS switching
- FET switching
- PIN diode switching

These three types of switchings are briefly discussed below.

3.3.1.1 MEMS switching

Now a days MEMS switches are widely used in frequency agile antennas. They have many advantages such as low loss, wide operating frequency range, low power consumption and have high power handling capacity. But they are much expensive and require high dc voltage to operate perfectly [16]. These switches have been perfectly used in many antennas to give proper frequency reconfiguration. For example the design made by Sunan *et al.*[17] consists of a dual band frequency reconfiguramicrostrip patch antenna integrated with MEMS. There are ten switches used in this design, five along each side of the rectangular patch, as shown in the figure.They are integrated to the diagonally fed square patch in order to control the operating frequency. At one edge end of the patch a rectangular stub is attached to produce fixed polarization.

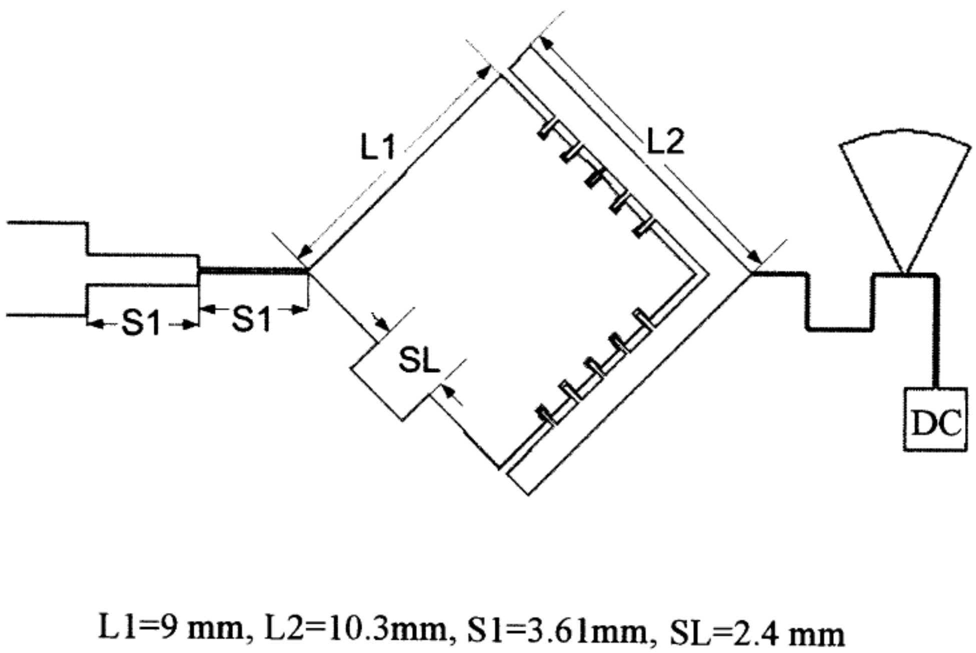


Figure 3.4 A frequency reconfigurable antenna integrated with MEMS switch (from [17])

In the above design frequency is changed by either switching OFF the MEMS switches (at that time the length of the side will be L1) or by switching ON the MEMS switches (the length will be L2). The tuning range obtained is 5.38% with 30 volt DC voltage requirement and very negligible current.

Similarly another frequency reconfigurable antenna using MEMS switch is shown in the figure 4.5. This antenna consists of a nested patched antenna designed for various applications such as GSM, GPS, bluetooth and wireless lan services [18].

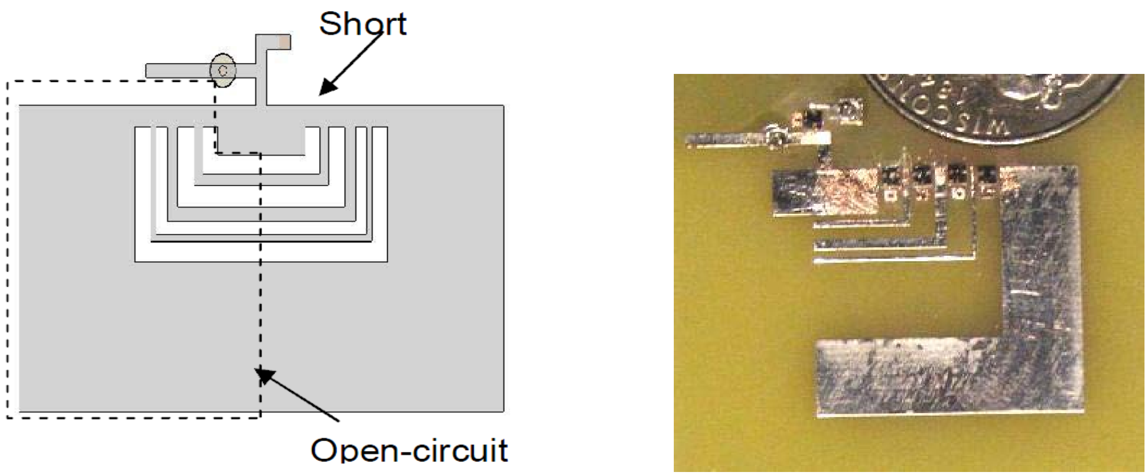


Figure 3.5 Design of mini nested patch antenna using MEMS [18]

By using MEMS switches different bands with center frequencies 2.4GHz and 5.2 GHz are obtained.

3.3.1.2 FET switching

Field effect transistors (FETs) can be also used in frequency reconfigurable antennas. The structure of a FET is shown in the figure 4.6. In FET current flows from source to drain, which is achieved by increasing the gate voltage.

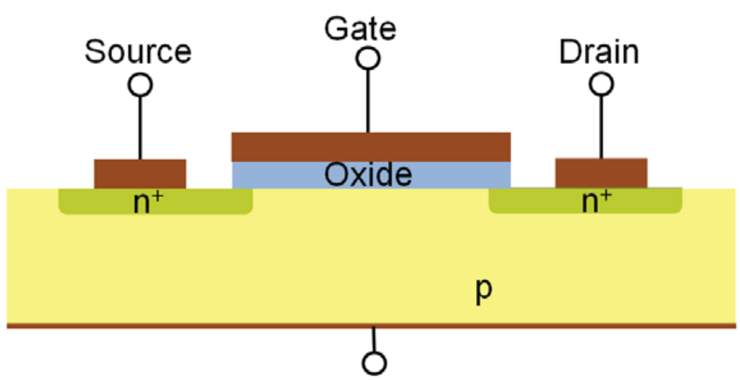


Figure 3.6 Structure of a FET

These are voltage controlled devices. FETs have advantages like less power consumption, low cost and provide very good switching condition. But they provide complex bias structure and reduce the radiation efficiency. Varactor diodes are also voltage controlled devices. For reconfigurability the voltage can be changed by changing the capacitance value. In [16] Mak *et al.* designed an antenna by using a GaAs FET to operate in the GSM, UMTS, bluetooth and 2.4 GHz WLAN bands.

3.3.1.3 PIN diode switching

PIN diodes are the most widely used electronic switches to obtain frequency reconfigurability. They have several advantages over other switching techniques. PIN diodes are inexpensive, which is significant in wireless communication. They have very low loss and good isolation ; they are easy to achieve; low package parasitic reactance; they possess high switching speed and their size is small compared to their wavelength. PIN diodes can also control large radio frequency signals using low power levels. PIN diodes have different package sizes which increase its functionality and they provide a simple DC bias network. Unlike FETs PIN diodes are current controlled devices, so power consumption is more than MEMS and FETs. In [16] Mak *et al.* designed the antenna and used all three types of switching i.e. MEMS, FET and PIN diodes to get frequency reconfigurability. Among all three PIN diode switches give the best radiation efficiency and resemble ideal switching condition. Sheta *et al.* [20] developed a compact tunable patch antenna with rectangular slots in the patch to have small size and increased tuning range. PIN diodes are used in this antenna to obtain frequency reconfigurability.

As shown in figure 4.7 PIN diodes are placed in between the antenna and some shorting posts. When they are switched ON each can be short circuited to the ground plane to obtain frequency reconfigurability.

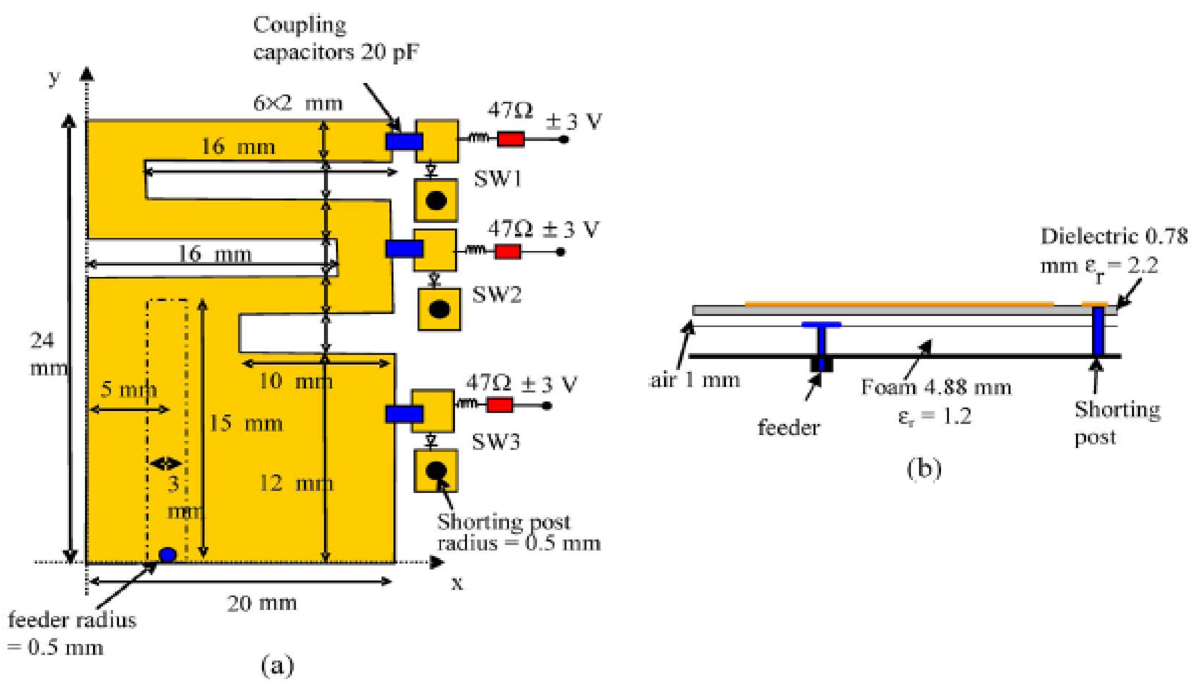
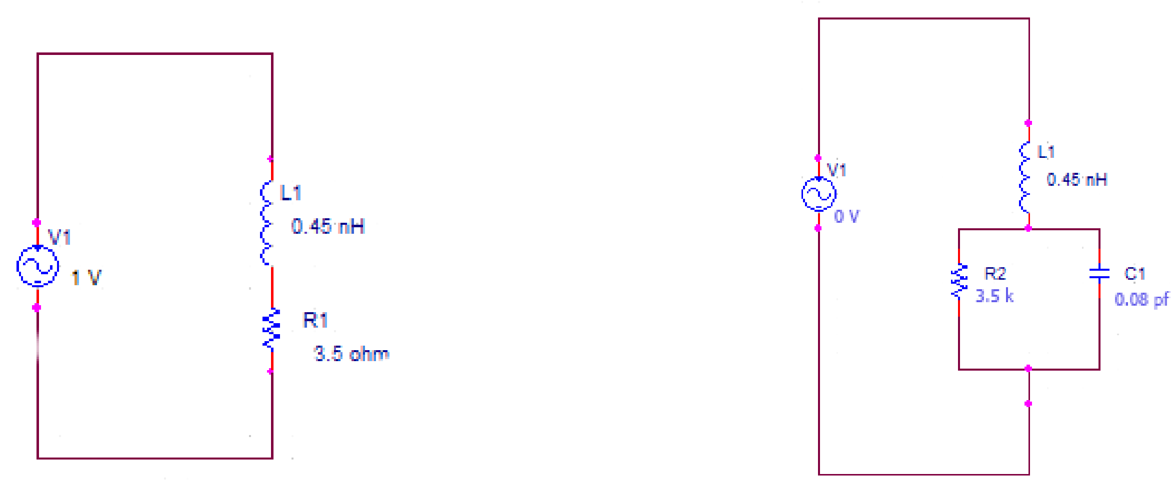


Figure 3.7 Frequency tunable rectangular patch antenna (a) top view (b) side view (from [20])

The ON OFF condition can be achieved by keeping the diode in forward bias or reverse bias condition. The circuits for forward bias and reverse bias condition are shown in the figure below.



(a) (b)

Figure 3.8 Equivallent circuit of PIN diode in (a) forward bias (b) reverse bias

3.3.2 Continuous tuning

Continuous tuning can be achieved by applying physical changes to the antenna. This provides any frequency of operation within its tuning range. To have continuous tuning the antenna usually applies 3 different chnages. They are

- Structural changes/ Mechanical changes
- Material changes
- Variable reactive loading

Large tuning range can be achieved by material change, but the most effective switching methor here is reactive loading. Because changing of material needs high DC supply and may be impractical to apply. For reactive loading, varactor diodes are used as switching elements in most of the cases. As varactor diodes are voltage devices they require less DC power supply, but in some cases they may consume more power.

Table 1 Summary of frequency reconfigurable techniques

Frequency Reconfigurable Techniques	Examples	Tuning ability and Tuning range	Attributes
Electronic switches	- Pin diodes - MEMS - FET	Discrete tuning ➢ MEMS-141% ➢ FETs- 84% ➢ PIN- 92%	• Low loss • Low voltage level • Easily integrated
Structural/Mechanical changes	- Colloidal dispersions -Mechanical actuators	Continuous tuning ➢ up to 57%	• Low loss • Slow response time • High actuation voltage
Material changes	- Ferrites - Ferroelectrics - Liquid crystals	Continuous tuning ➢ Ferrites-133%	• High loss • Tempurature Sensitive • Large DC bias
Variable reactive	- Varactors	Continuous tuning ➢ Varactor-63% ➢ Varactor-115% (Sim) ➢ Varactor and PIN diode-112%	• Some losses • Low/medium bias levels • Easily integrated

Chapter 4

Frequency reconfigurable Dielectric resonator antennas

4.1 Introduction

In this chapter two different frequency reconfigurable antennas are presented. In 1st antenna the reconfigurability is obtained using ideal switches and in the second antenna pin diodes are used for switching purpose. Simlation and parametric studies are done using CST 2012 and optimum designs are presented. From the simulation results frequency vs. return loss curve and radition pattern curves are analyzed and discussed below.

4.2 Design 1

In the 1st design the theory behind an edge grounded dielectric resonator antenna is applied [22]. The structure of an edge gronded DRA is shown in the figure 5.1. One of its edge is shorted to the ground plane. Because of this shorting wall, the electric fields are forced to be normal to the conductor and the magnetic fields are forced to be tangential to the conductor as shown in the figure. Also by using the shorting wall concept the resonant frequency can be decreased. For example in the proposed design, without shorting the wall a resonant frequency of 5 GHz is obtained, but by shorting it the resonant frequency is decreased to 3.5 GHz.

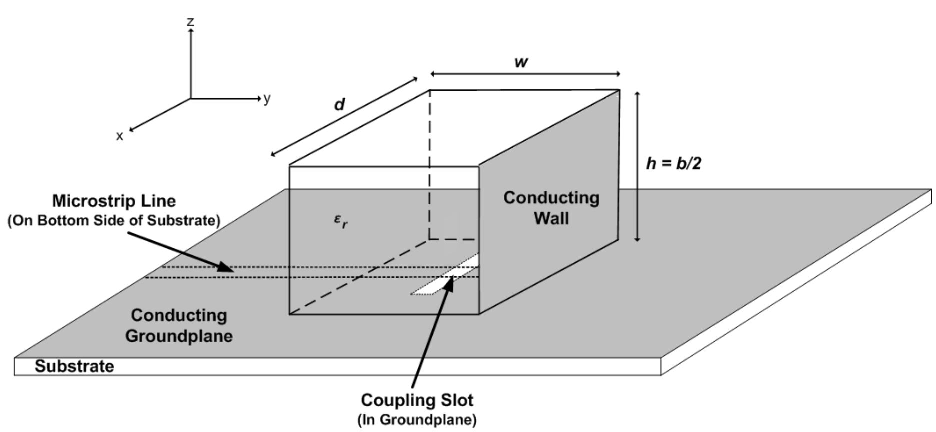


Figure 4.1 Rectangular DRA with one edge connected to ground [22]

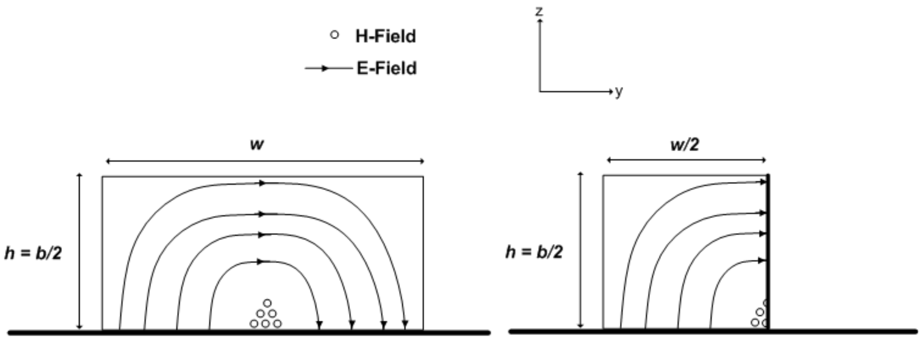


Figure 4.2 Field configuration in the above DRA

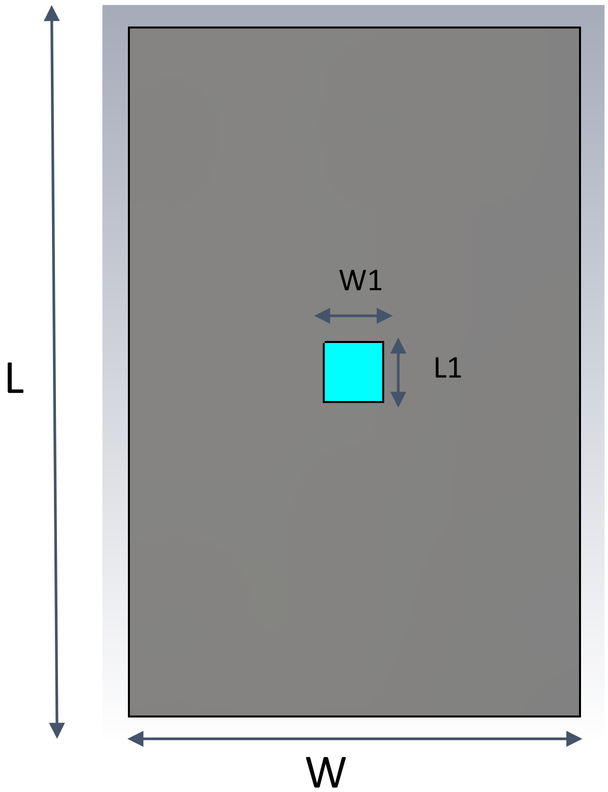
4.2.1 Geomatry of the proposed design

The antenna consists of a rectangular DRA with dielectric constant ε_r = 10. Below to the DRA a very wide dimension ground plane is placed (infinite ground plane concept is applied). A subatrate of dielectric constant ε_r = 3.38 with width 0.508 is used below to the grond plane. Here aperture coupling feeding technique is used.

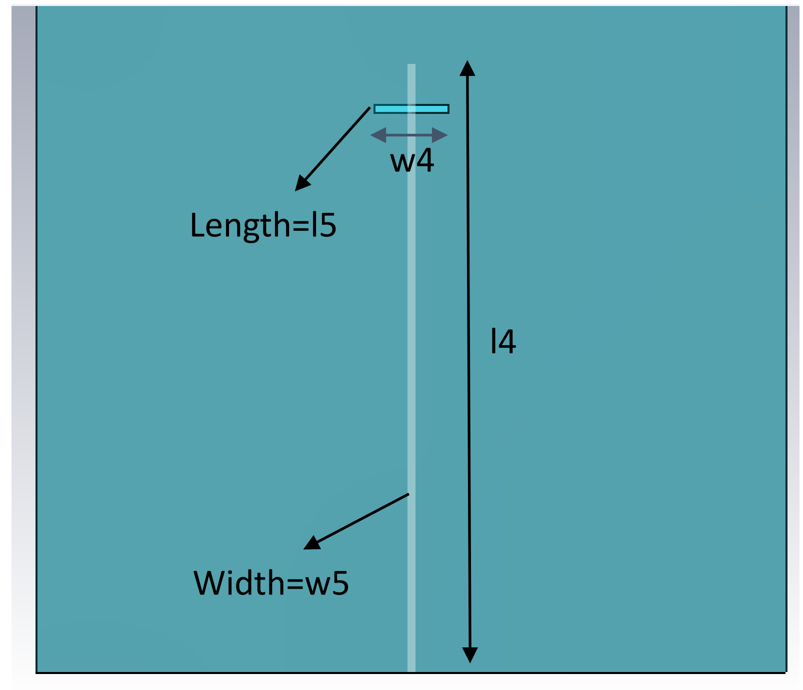
In aperture coupling ground plane is placed in between the substrate and the DRA, this isolates the feed network from the radiating element and thereby minimizes interference of spurious radiation. A slot is created in the ground plane below to the DRA through which the resonator radiates. The length and width of the slot control the amount of coupling from the feed line to the DRA. When designing, it should be noted that we have to make the length of the slot large enough to allow required amount of coupling between the DRA and feed line and the width of the slot small enough to avoid any backlobe component.

In the proposed design the dimension of the DRA is taken as 13mm$\times$ 13mm $\times$ 10mm. The dimension of the grond plane is 100 mm × 150 mm with thickness of 0.05 mm. The substrate has same dimension with thickness of 0.508 mm. Below to the substrate a feed line of length 81 mm and width 1.18 mm is placed. The apeture made in the ground plane has width 10 mm and length 1 mm. The apeture is placed at the center of the DRA so that maximum radiation will occur.

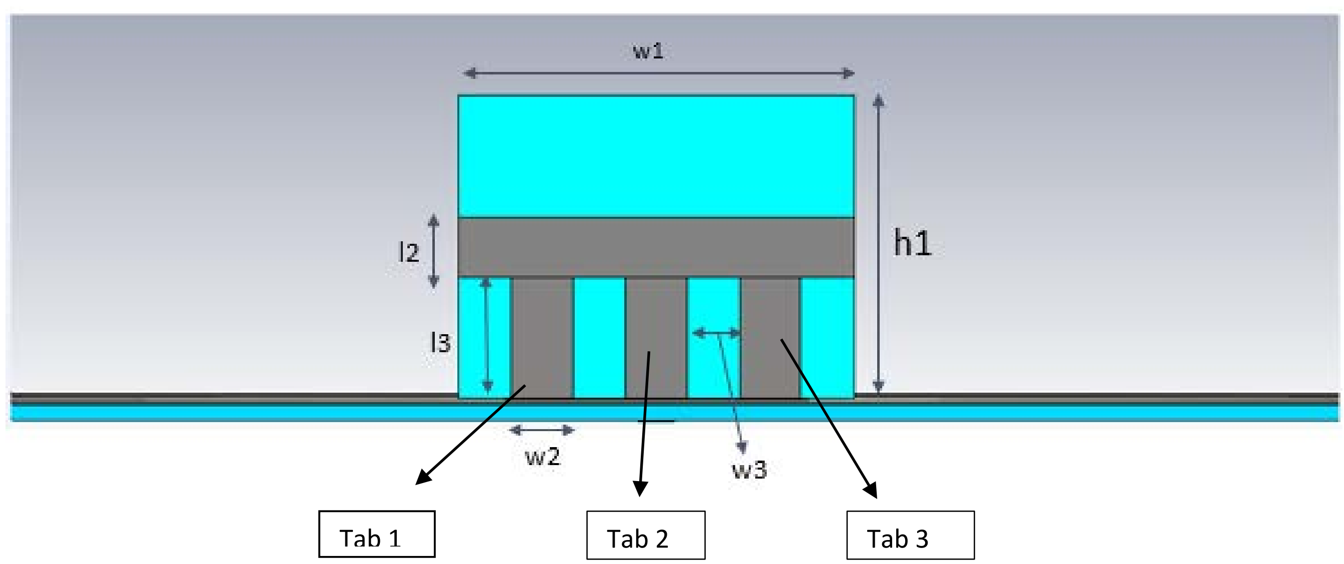
The design of the antenna is shown in the figure below.



(a)



(b)



(c)

Figure 4.3 The proposed antenna (a) front view (b) rear view (c) side view

Table 4.1 Dimensions of the proposed 1st design

Parameters	Dimensions (mm)	Parameters	Dimensions (mm)
W	100	w2	2
L	150	l2	2
w1	13	w3	1.75
l1	13	l3	4
h1	10	w4	10
w5	1.18	l5	1

4.2.2 Simulation results

In the above design only DRA is first excited and a frequency of 4.945 GHz with return loss value -22.59 dB is obtained. After adding two microstrip strips on the two sides of the DRA similar result with return loss -26.59 is obtained. .

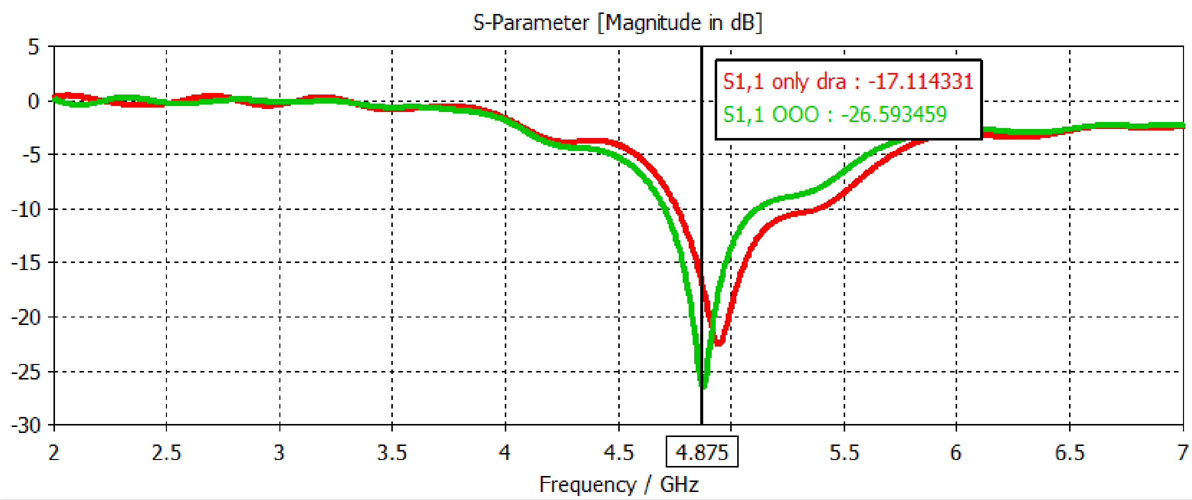


Figure 4.4 Return loss curves of only DRA and DRA with microstrip strips on two sides

To obtain frequency reconfigurability 3 shorting tabs are used (as shown in figure 5.3 (c)) on one side of the DRA. The tabs are used to short one side of the DRA to ground plane. Using these 3 tabs six unique antenna structures are obtained, each resonating at different frequency. Initially the parametric study is performed by taking 3, 4, 5 tabs and optimum result is obtained with 3 tabs.

4.2.2.1 Return loss vs frequency curve

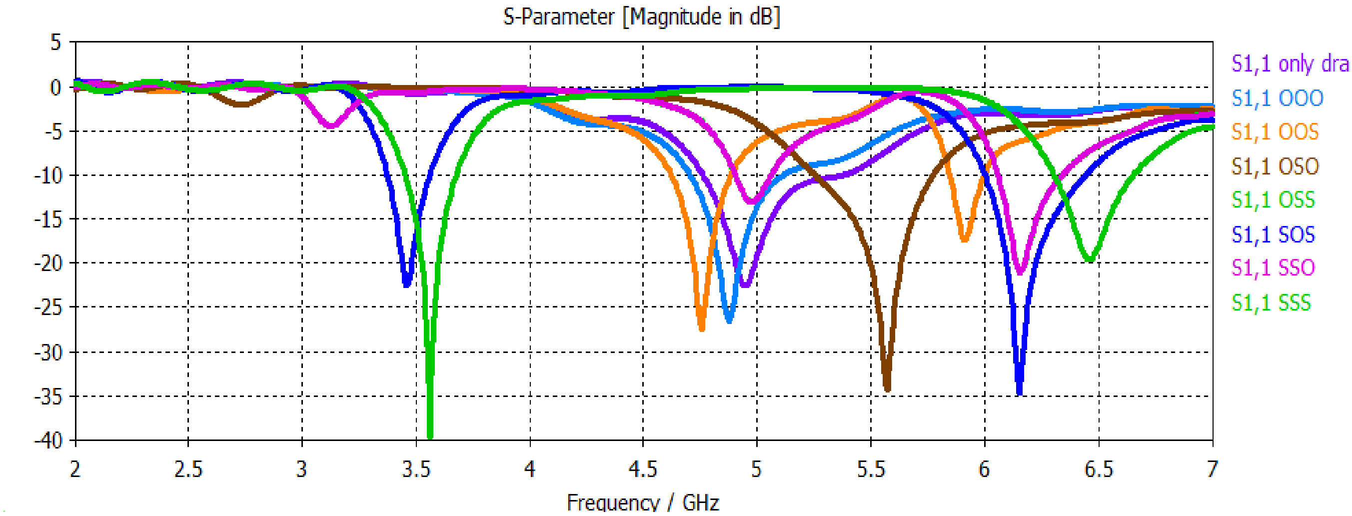


Figure 4.5 Retutrn loss plot of the antenna at 6 different conditions

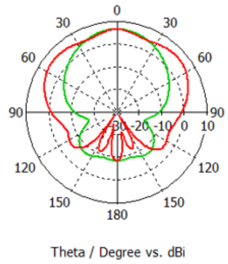
Here 3 tabs are used which give 6 unique results that is represented by OOS, OSO,OSS,SOS,SSO,SSS. O means open and S means short. So starting from left if tab 1 is open and the other twos are shorted then this is called OSS. Similarly others are obtained by switching different tabs.

Table 4.2 Frequency of operations at different operating conditions

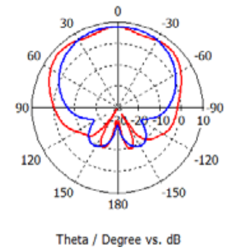
Tab 1	Tab 2	Tab 3	Conditions	Frequency of operation (GHz)	
Open	Open	Open	OOO	4.495	
Open	Open	Short	OOS	4.755	5.92
Open	Short	Open	OSO	5.57	
Open	Short	Short	OSS	6.15	4.97
Short	Open	Short	SOS	6.15	3.46
Short	Short	Open	SSS	6.16	4.47
Short	Short	Short	SSS	3.56	6.45

As we can see at only at OOO and OSO single band of frequency is obtained. At all other conditions dual bands are obtained. So this antenna can be used as dual band frequency reconfigurable antenna. The radiation pattern at each frequency is shown below.

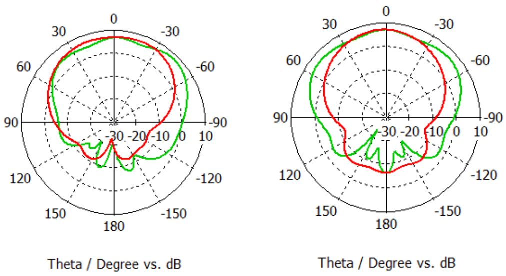
4.2.2.2 Radiation pattern plots



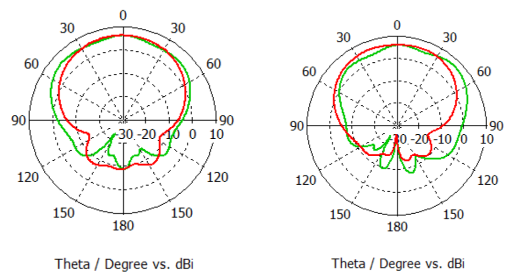
(a) At frequency 4.875 GHz (ooo)



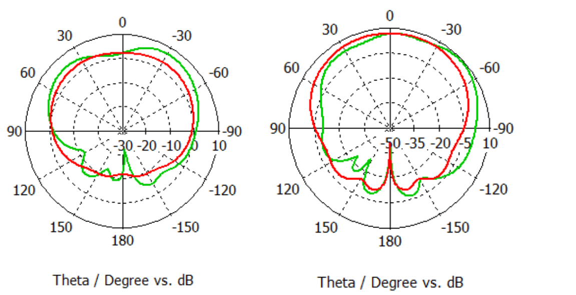
(b) At frequency 5.57 GHz (oso)



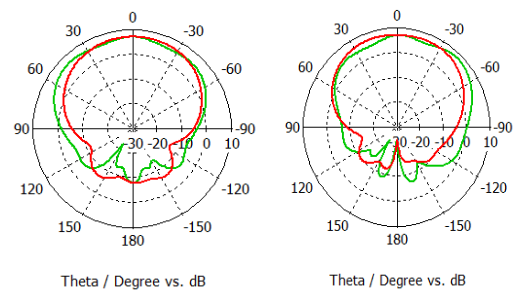
(c) at frequency 5.92 GHz and 4.75 GHz (oos)



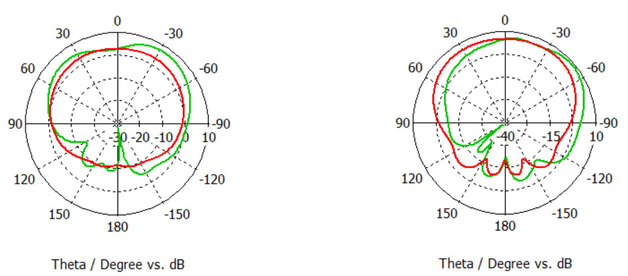
(d) at frequency 4.97 GHz and 6.16 GHz (oss)



(e) at frequency 3.46 GHz and 6.15 GHz (sos)



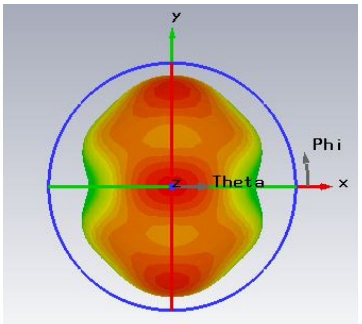
(f) at frequency 4.97 GHz and 6.15 GHz (sso)



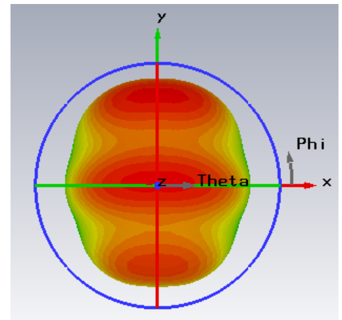
(g) at frequency 3.56 GHz and 6.45 GHz (sss)

Figure 4.6 E plane and H plane patterns at different frequencies

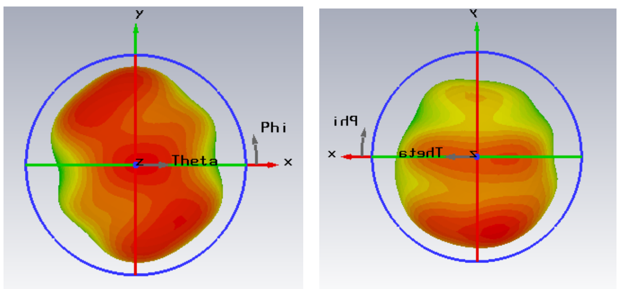
3D radiation pattern plots



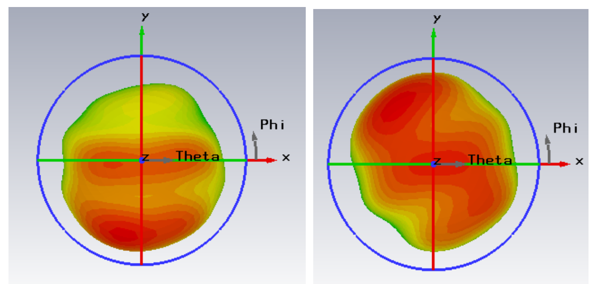
(a) at 4.94 GHz (OOO)



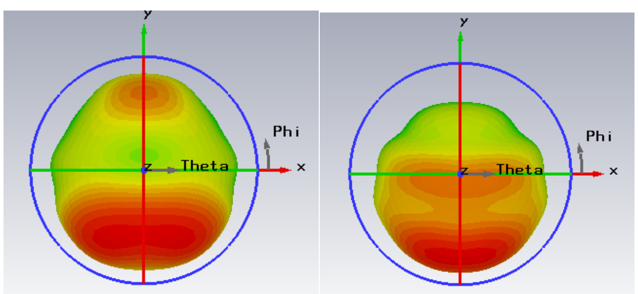
(b) at 5.57 GHz (OSO)



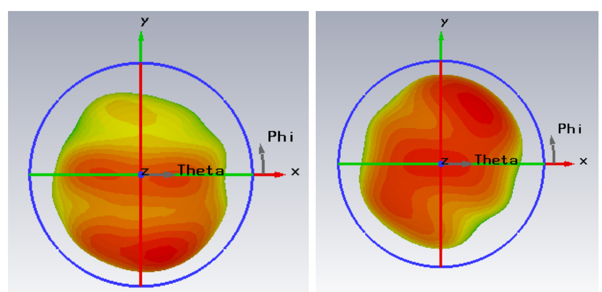
(c) at 4.755 GHz and 5.92 GHz (OOS)



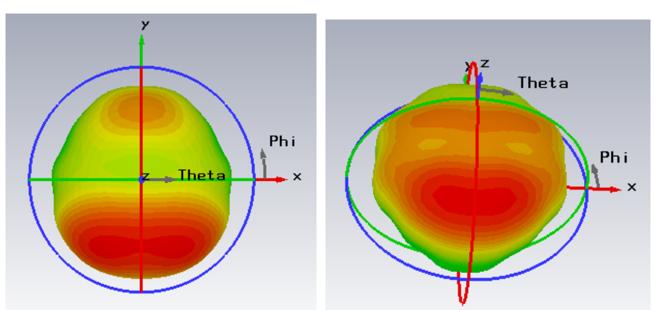
(d) at 6.15 GHz and 4.97 GHz (OSS)



(e) at 3.46 GHz and 6.15 GHz (SOS)



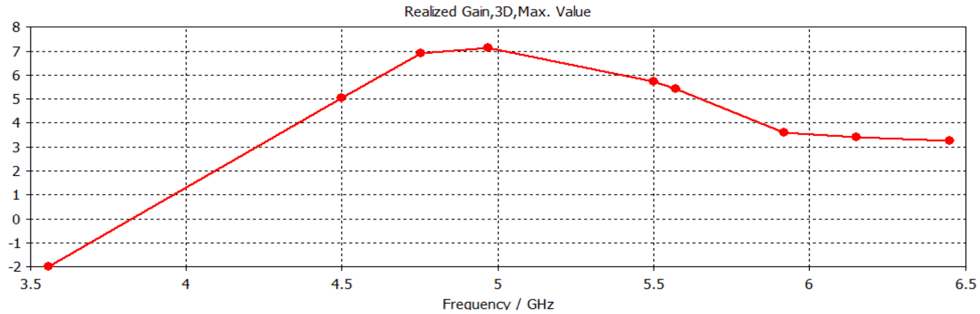
(f) at 4.97 GHz and 6.15 GHz (SSO)



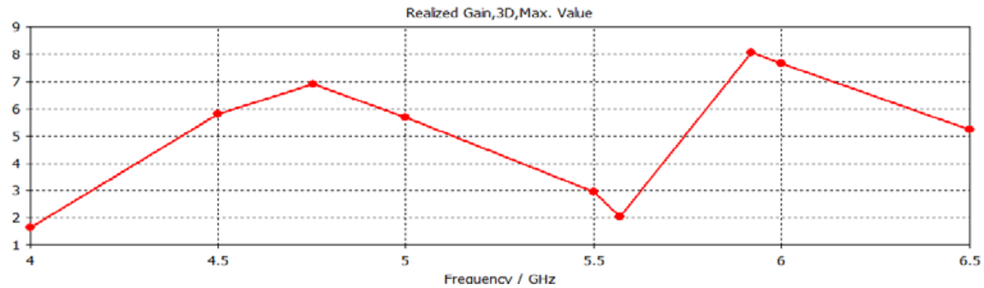
(g) at 3.56 GHz and 6.45 GHz (SSS)

Figure 4.7 3D plots of radiation pattern at different frequencies

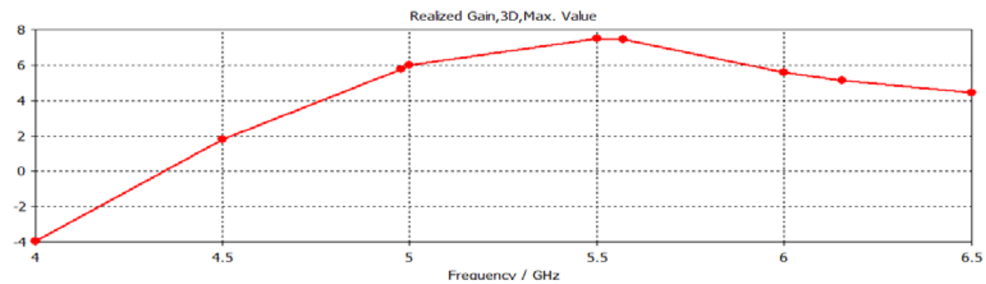
4.2.2.3 Gain vs frequency plots



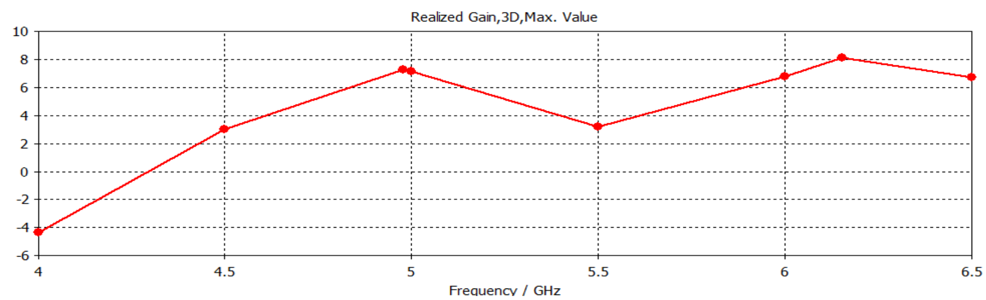
(a) OOO



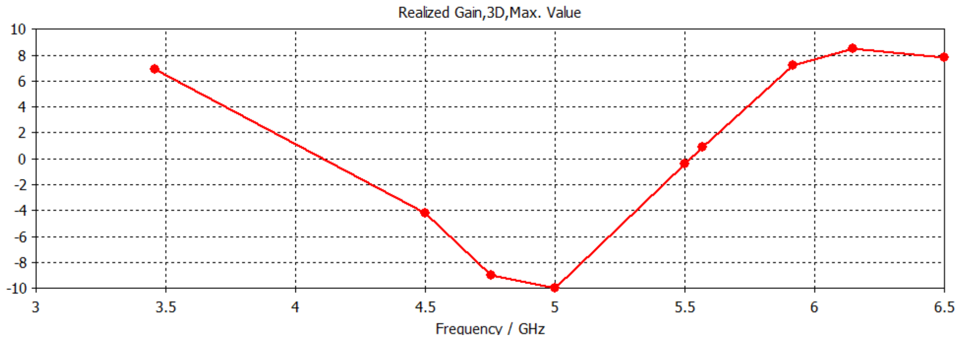
(b) OOS



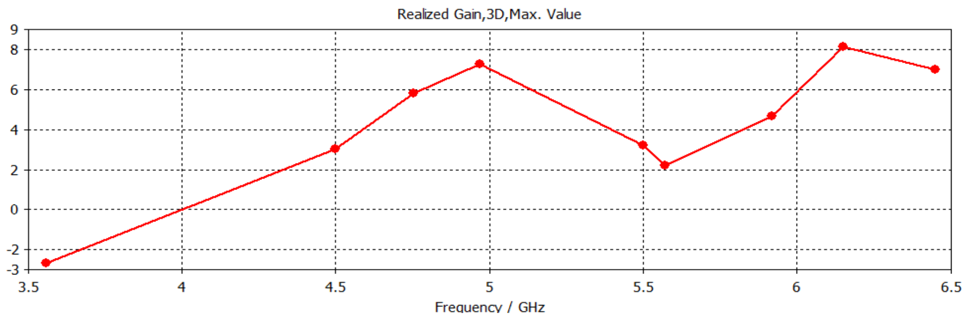
(c) OSO



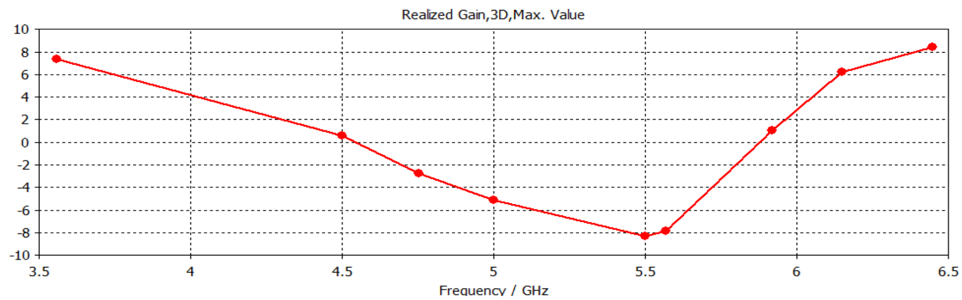
(d) OSS



(e) SOS



(f) SSO



(g) SSS

Figure 4.8 Realized gain vs frequency plots

4.2.3 Summary

Table 4.3 all antenna parameters at specific frequencies for design 1

Conditions	Resonant frequency(GHz)		Gain (dBi)		Radiation efficiency	
OOO	4.945		7.182		91.24%	
OOS	4.755	5.92	6.924	8.057	91.08%	89.9%
OSO	5.57		7.481		89.2%	
OSS	6.155	4.977	7.184	6.486	89.3%	89%
SOS	6.15	3.46	6.908	8.520	91.2%	91%
SSO	6.155	4.97	7.298	8.137	89.3%	89.12%
SSS	3.56	6.45	7.344	8.397	90%	89.4%

Chapter 5

H shaped frequency reconfigurable DRA using coplanar waveguide (CPW) feed

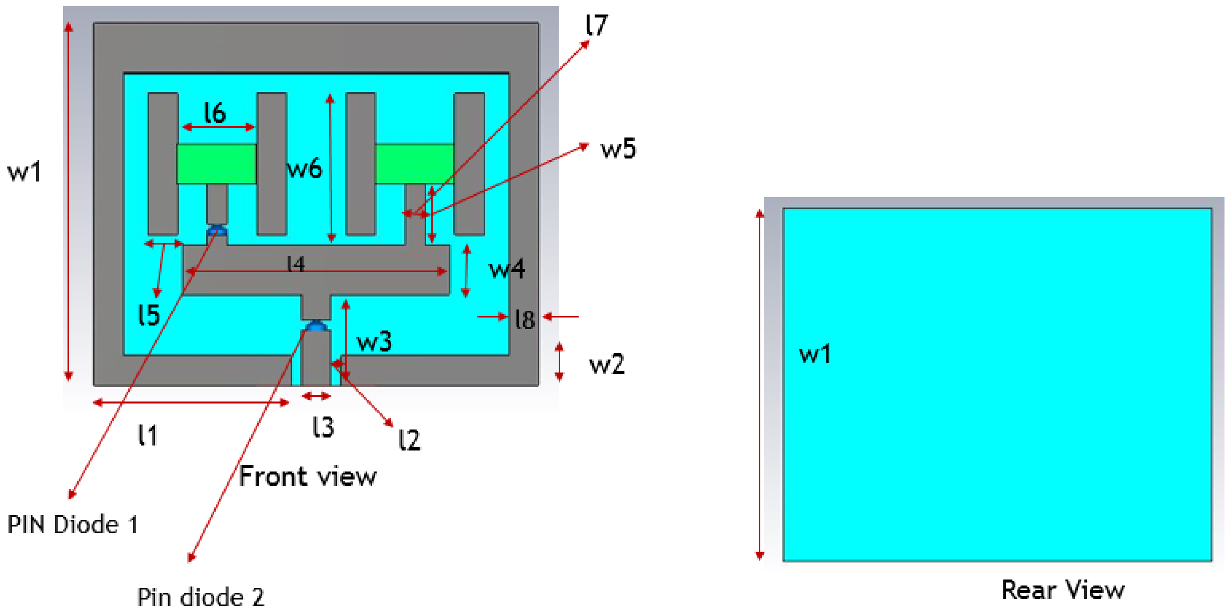
In this design two dielectric resonators of dielectric constant 15 are used. They are fed using CPW (coplanar waveguide) feeding technique. CPW feeding method has advantages like they have low loss, less dispersive nature, easy fabrication, low surface wave and it offers a more elegant and efficient mechanism to the DRA. In this design two PIN diodes are used for switching purpose, they are placed on the lines connecting the feed network to the DRA.

By using PIN diodes 3 modes of operation are obtained, i.e. OFF- ON, ON-OFF and ON-ON. The ON and OFF conditions can be achieved by forward and reverse biasing of PIN diodes. When the diode is in forward bias, the switch has a very low impedance and acts as short circuit. Similarly when it is in reverse bias, the switch acts as open circuit. The equivalent circuits of the PIN diodes in forward bias and reverse bias are discussed in chapter 3.

5.1 Design 2

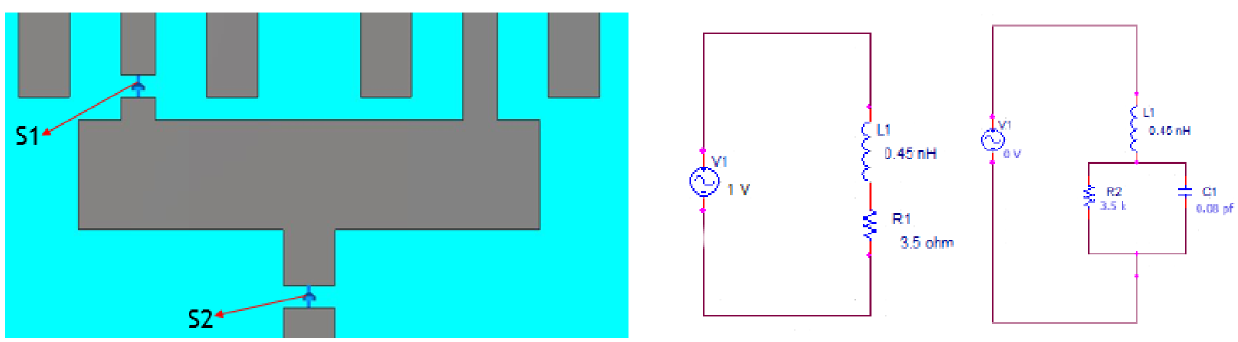
5.1.1 Geometry of the proposed antenna

Geometry of the proposed antenna is shown in the figure 5.9. The antenna consists of two DRs of dielectric constant 15. The dielectric resonators are placed on two sides of the antenna. CPW feeding technique is used to excite the DRA. The DRA is covered by two microstrip slots on two sides of it. Below to the feed line a single layer of Taconic substrate with dielectric constant 3.2 and thickness of 1.6 is placed. The antenna is symmetrical in the vertical direction, whose main structure is an H shaped DRA with CPW feed.



(a) (b)

Figure 5.1 (a) Front view and (b) rear view of the proposed antenna



(a) (b)

Figure 5.2 (a) PIN diodes in the design (b) equivalent circuit of PIN diodes in forward bias and reverse bias

The antenna parameters are optimized and obtained as follows.

Table 5.1 proposed antenna (design 2) parameters

Parameters	**Dimensions(mm)**	**Parameters**	**Dimensions(mm)**
l1	20	w1	36
l2	1.5	w2	5

l3	2	w3	9
l4	22	w4	5
l5	3	w5	6
l6	8	w6	14
l7	2	w7	4
l8	1	h	1.6

Three operating conditions are achieved by switching the PIN diode switches S1 and S2.

Table 5.2 Different modes obtained by switching the PIN diodes

Modes	**S1**	**S2**
1	Off	On
2	On	Off
3	On	On

5.1.2 Simulation results

5.1.2.1 Return loss curves at three different operating modes

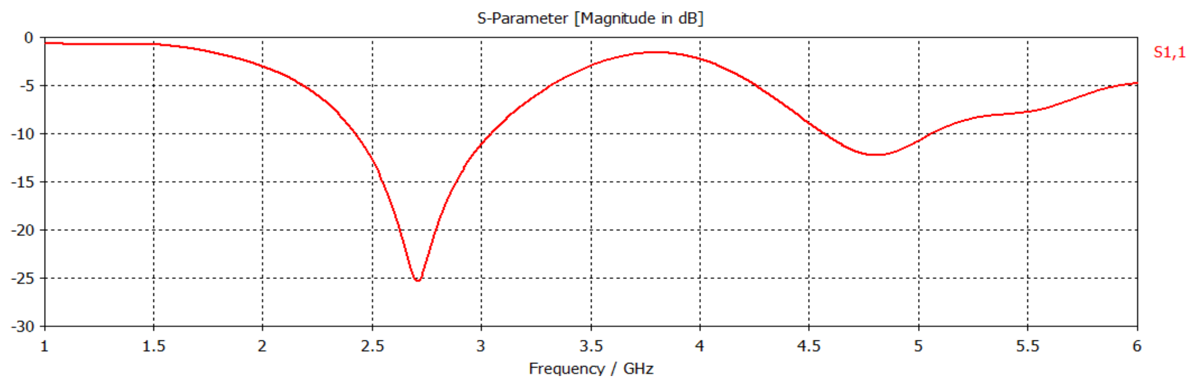


Figure 5.3 Return loss vs. frequency plot in OFF ON state

The above figure shows OFF ON state; 2 bands with center frequencies 2.7 GHz for WLAN application and 4.8 GHz for INSAT (Indian national satellite system) application are obtained.

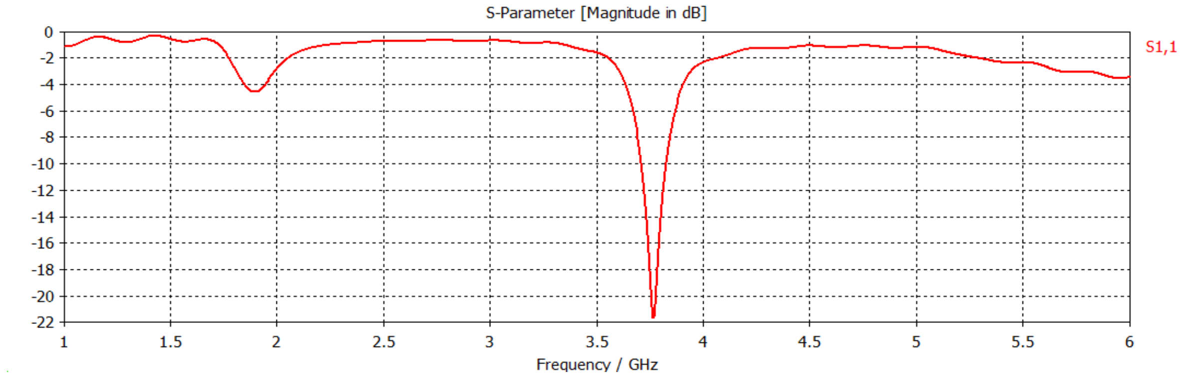


Figure 5.4 Return loss vs. frequency plot in ON OFF state

In the above mode a single narrow band with center frequency 3.7 GHz is obtained for WLAN and international mobile telecommunications (IMT) applications.

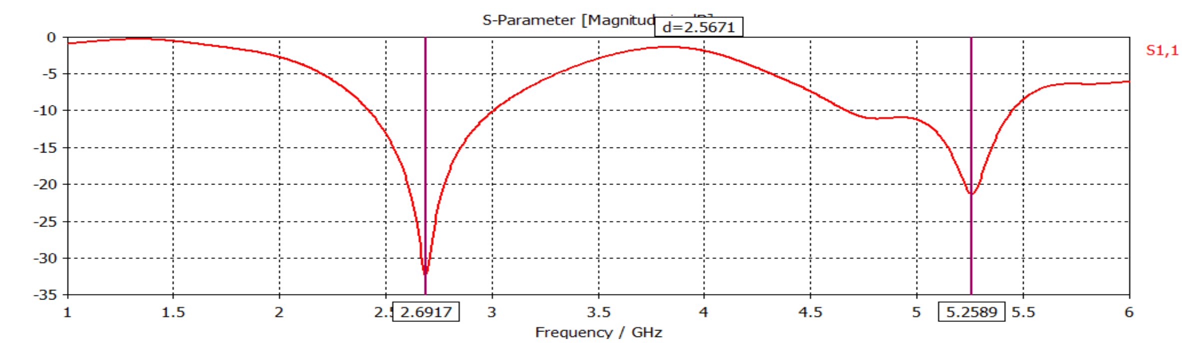
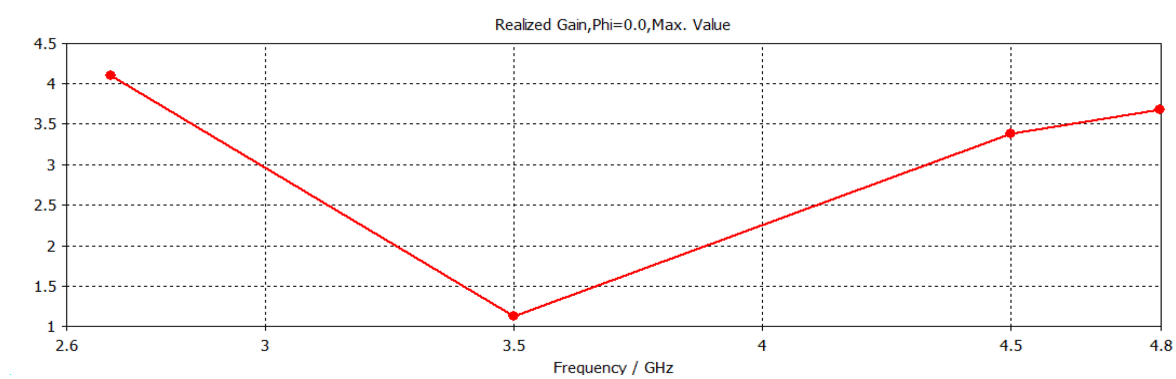


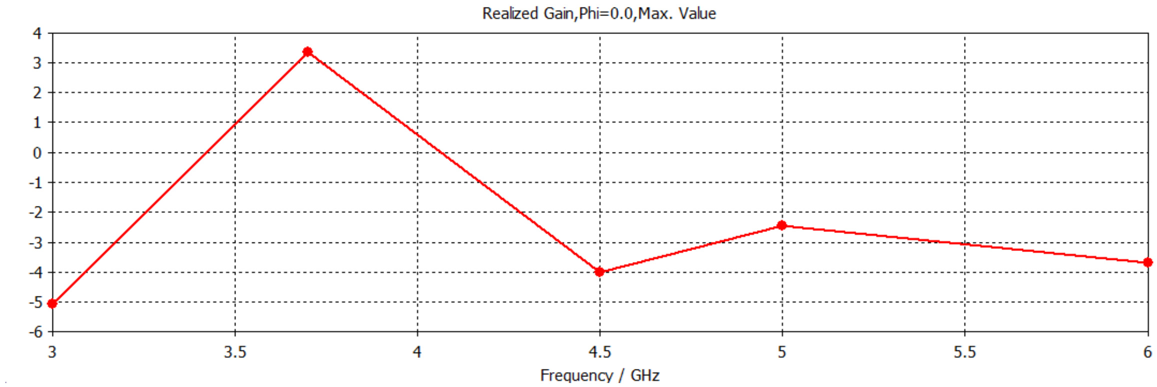
Figure 5.5 Return loss vs. frequency plot in ON ON state

In this mode a dual band with frequencies 2.6917 and 5.2589 is obtained for WLAN applications

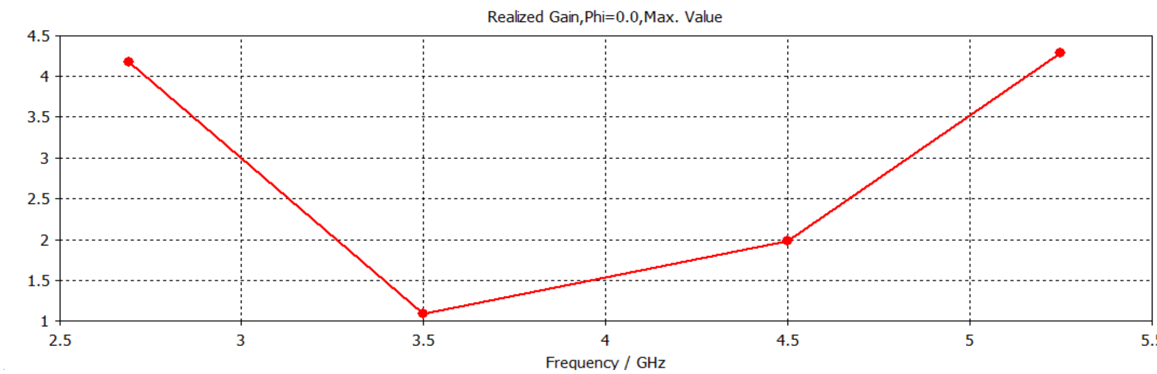
5.1.2.2 Gain vs. frequency plots



(a) OFF ON



(b) ON OFF



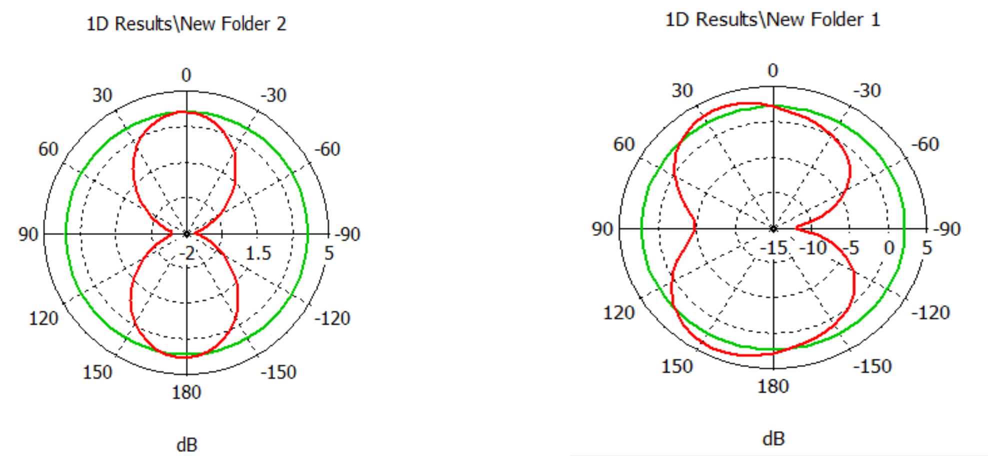
(c) ON ON

Figure 5.6 Gain vs. frequency plots at (a) OFF ON (b) ON OFF (c) ON ON states

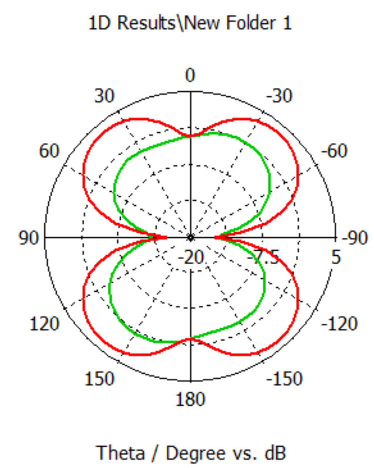
Table 5.3 Realized gain at different frequencies

Modes	Resonant frequency(GHz)		Gain(dBi)	
OFF-ON	2.7	4.8	4.2	3.6
ON-OFF	3.7		3.1	
ON-ON	2.69	5.25	4.2	4.6

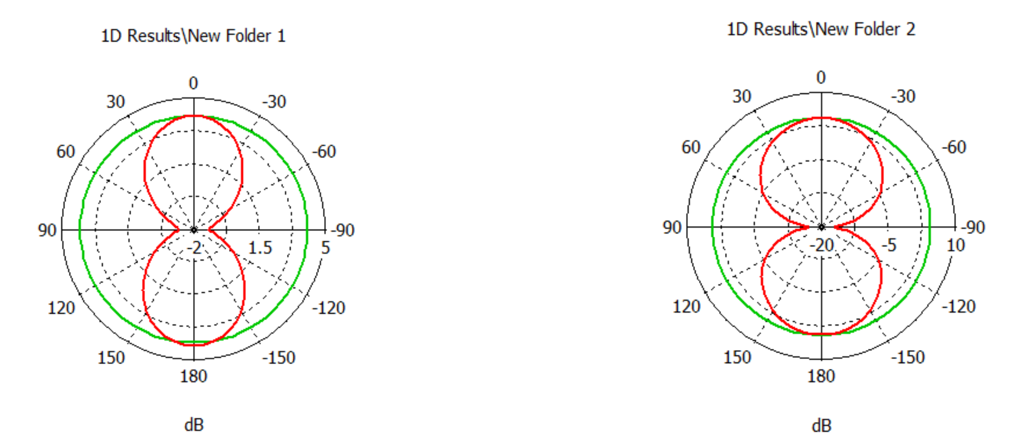
5.1.2.3 Radiation pattern plots



(a) E plane and H plane radiation pattern in OFF-ON state at 2.7 GHz and 4.8 GHz frequencies



(b) E plane and H plane radiation pattern in ON-OFF state at 3.7 GHz

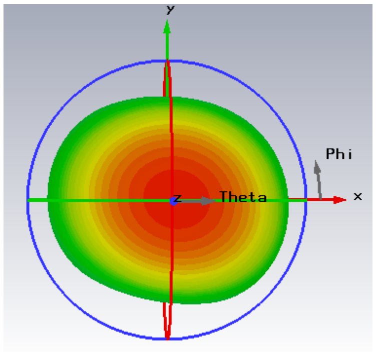


(c) E plane and H plane radiation pattern in ON-ON state at 2.69 GHz and 5.25 GHz frequencies

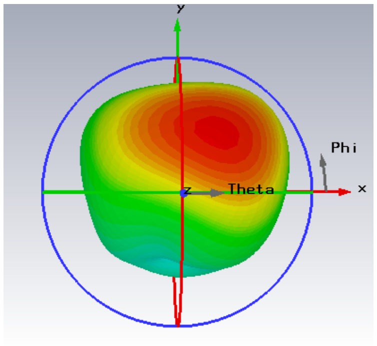
Figure 5.7 radiation pattern in (a) OFF ON (b) ON OFF (c) ON ON states

In the above figure at each frequency E plane and H plane is observed. The H plane is circular which means that the antenna is omnidirectional. The E plane is showing the maximum value of electric field any a direction. The dumbbell shape shows the direction of these radiation. It represents the major lobe of the antenna radiation pattern.

Below 3D plot of the radiation pattern is shown. The red color shows the maximum radiation in the antenna.

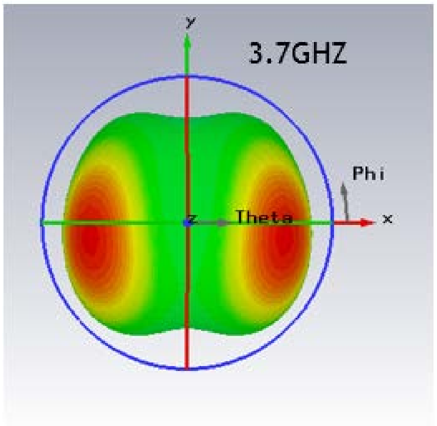


(1)

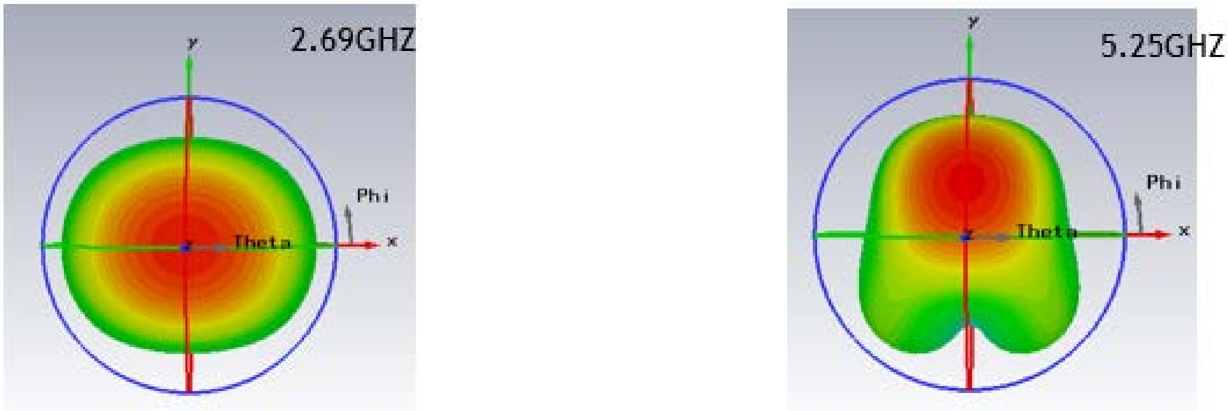


(2)

(a) Radiation patterns in OFF-ON state at (1) 2.7 GHz and (2) 4.8 GHz



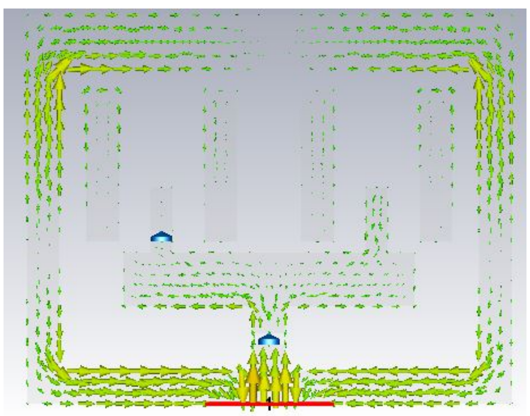
(b) Radiation pattern in ON OFF state



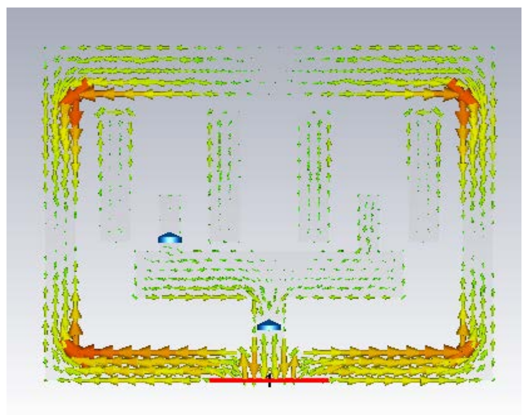
(c) Radiation patterns in ON OFF state at (1) 2.69 GHz and (2) 5.25 GHz

Figure 5.8 Radiation pattern 3D plots in different states

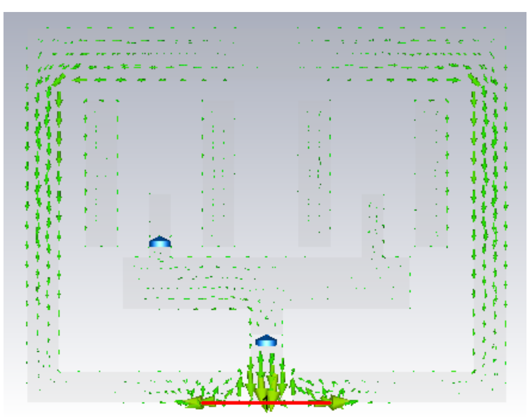
5.1.2.4 Surface current plots



(a) OFF-ON



(b) ON-OFF



(c) ON-ON

Figure 5.9 Surface current plots at (a) OFF-ON (b) ON-OFF (c) ON-ON state.

The surface current plots are shown in the above figure. Surface current gives the direction current flow from the input port to the radiating element. We can also find the resonating mode, polarization, current distribution from the above plots. Here the antenna is linearly polarized and the resonating mode isTE_{110}.

5.1.2.5 Summary table

Table 5.4 Value of different parameters at the resonant frequencies

MODES	**RESONANT FREQUENCY(GHZ)**	**BAND**	**GAIN(dB)**	**IMPEDANCE BANDWIDTH**
OFF ON	2.7	2.45-3.01	4.2	20%
	4.8	4.6-5	3.6	8%
ON OFF	3.7	3.63-3.78	3.1	4%
ON ON	2.6	2.45-2.99	4.2	21%
	5.25	4.7-5.5	4.6	15%

In the above design a frequency reconfigurable DRA with CPW feeding is presented and analyzed. The antenna supports two dual bands and one single band of operation. Switching condition is achieved by using two PIN diodes, which give three operating modes. So three band of operations are obtained using this antenna which can be used in WLAN, IMTS and INSAT applications.

Design 3

5.2 Aperture coupled dielectric resonator antenna with power divider

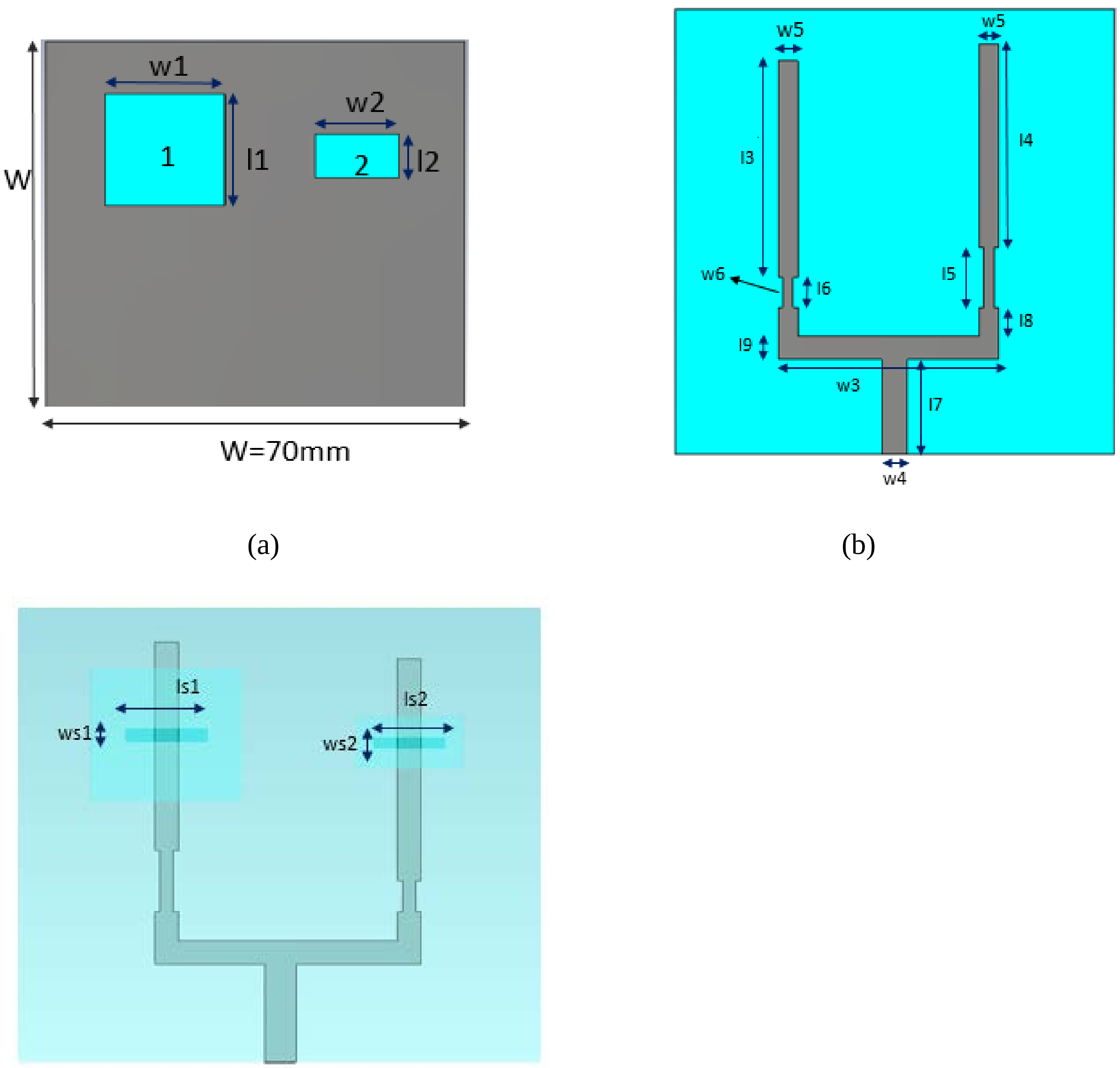
5.2.1 Geometry of the proposed antenna

The structure of the antenna is shown in the figure 6.10 below. The antenna is designed on a FR4 substrate of dielectric constant 4.4 and thickness 1.6 mm. In this design, two dielectric resonators of different dimensions, but same dielectric constant i.e. 10 are used. The dielectric resonators are placed above a ground plane of thickness 0.05 mm. Here aperture coupling feeding technique is used to excite the DRAs. To excite two dielectric resonators, two aperture slots are made in the ground plane below to the corresponding DRA. The feed network is designed below to the substrate as shown in the figure. To excite both the DRAs at the same time, here power divider concept is used. The feed network, connecting the input source to the dielectric resonators, is divided in to two parts each part for one DRA. If we consider impedance of the line is 50 Ω, then after dividing, each side has a new impedance of 100 Ω. So to make it again 50 Ω quarter wavelength transformers are used on both sides of the feed network. Therefore the power can be equally transmitted to both the dielectric resonators.

In this proposed design first of all the antenna is designed without any switches and its various results are studied. One single band at a frequency of 2.9 GHz for WLAN application is obtained.

The 1st DRA has dimensions of 20 mm × 20.3 mm × 6.7 mm and the second DRA has dimensions 14 mm × 8 mm × 8 mm. Both have dielectric constants 10.

Later in the same antenna, two PIN diodes are used on two sides of the feed line to obtain frequency reconfigurability. By using PIN diodes, resonators can be excited at different times and different operating modes can be achieved by switching the diodes. Here aperture coupling is used which offers advantages like low spurious radiation, less surface wave, easy fabrication, polarization purity etc.



(a) (b)

(c)

Figure 5.10 Design of the proposed antenna (a) Front view (b) Rear view (c) aperture slot

The length and width of the aperture are varied to get optimum result and the dimensions provided here are optimized. Initially both the antennas are designed to operate at different frequencies and the quarter wavelength transformers are designed at that frequencies. The power divider is separately designed and simulated using CST studio suite 2012 and then applied in the antenna. The dimensions are given in the table below.

Table 5.5 Dimensions of the proposed antenna

Parameters	**Value(mm)**	**Parameters**	**Value(mm)**	**Parameters**	**Value(mm)**
w1	20	w6	1.633	l5	9.43
w2	14	l1	20.3	l6	4.78
w3	35.1	l2	8	l7	15
w4	4.1	l3	34	l8	5
w5	3.1	l4	32	l9	3.6
ls1	11	ls2	8	$\mathcal{E}_{r1}$	10
ws1	2	ws2	1.7	$\mathcal{E}_{r2}$	10

The DRA is designed using the following formulas.

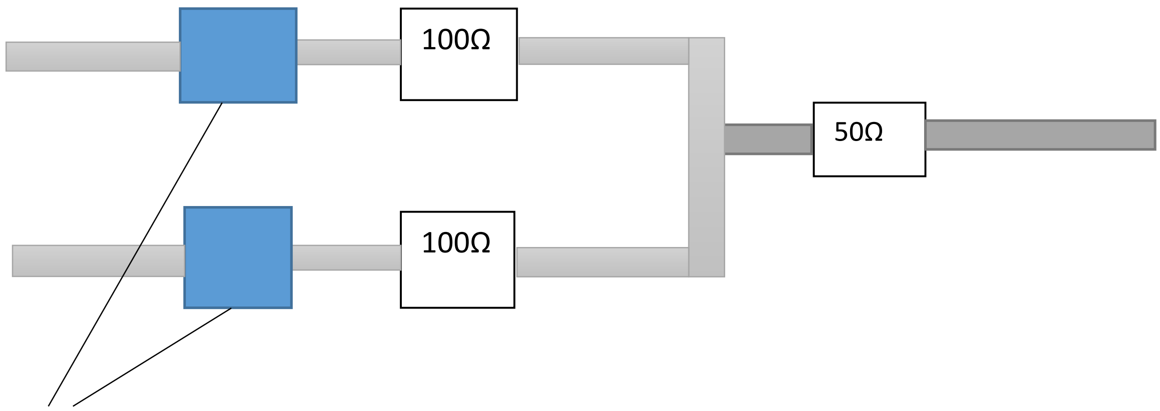
$$k_x tan\,(k_x d/2) = \sqrt{(\varepsilon_r - 1){k_0}^2} - {k_x}^2$$

Where $k_0 = \frac{2\pi}{\lambda_0} = \frac{2\pi f_0}{c}$, $k_y = \frac{\pi}{w}$, $k_z = \frac{\pi}{b}$ and ${k_x}^2 + {k_y}^2 + {k_z}^2 = \varepsilon_r {k_0}^2$

5.2.2 Feed line design

In this design since 2 dielectric resonators are used, to provide them same power at a time a power divider is needed. The feed line is designed to have impedance of 50 Ω (since the cable used for measurement has impedance of 50 Ω). When the feed line is divided in to two parallel parts each side now have impedance of 100 Ω. To make it again 50Ω quarter wavelength transformers are used. Quarter wavelength transformers are nothing but transmission lines with desired characteristic impedance. They are basically used to match the antenna with the transmission line. To have a match the characteristic impedance of the transformer (Z_1) should be

$Z_1 = \sqrt{R_{in} Z_0}$, Where Z_0 is the characteristic impedance of the line and R_{in} is the input impedance of the antenna.



Quarter wavelength transformer

The length and width of the transformer is calculated by using the following formulas.

Length= $\frac{\lambda_g}{4}$, λ_g is guided wavelength and its value $\lambda_g = \frac{\lambda_0}{\varepsilon_{reff}}$

Width = $\frac{8e^{A} \times h}{e^{2A} - 2}$, h is height of the substrate,

Where A = $\frac{Z_1}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r + 1}{\varepsilon_r - 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$

5.2.3 Simulation results

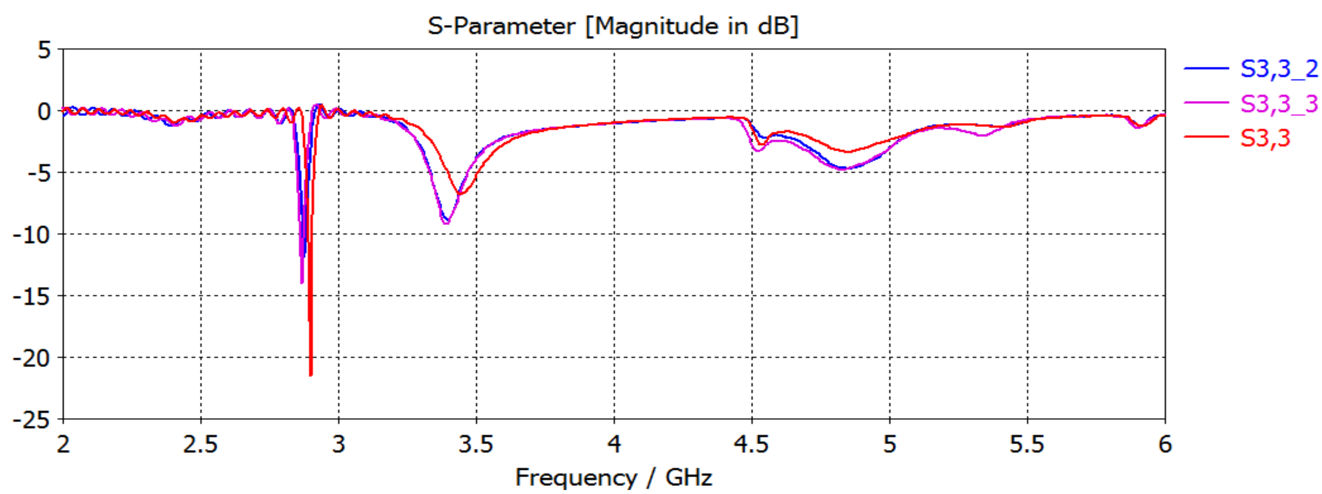
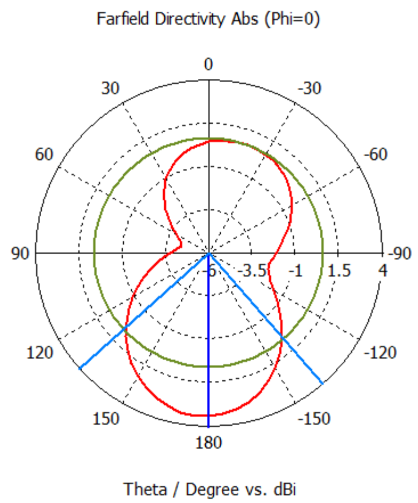
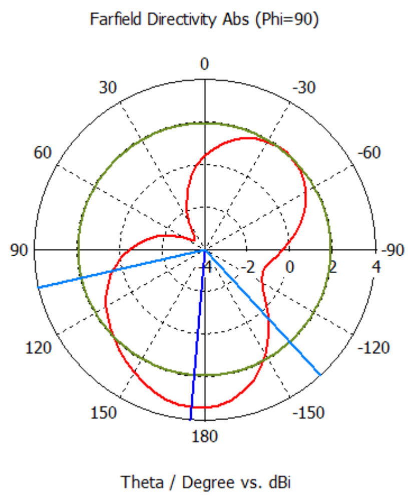


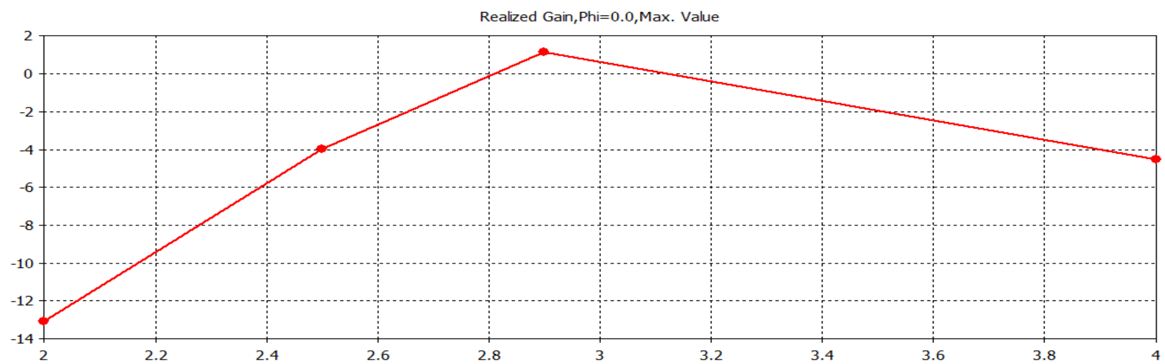
Figure 5.11 Return loss vs. frequency plot

In the above diagram it is shown that a narrow band centered with frequency 2.9 GHz is obtained for WLAN applications. The Return loss value is found to be -22 dB and the impedance bandwidth of the antenna is 4%.

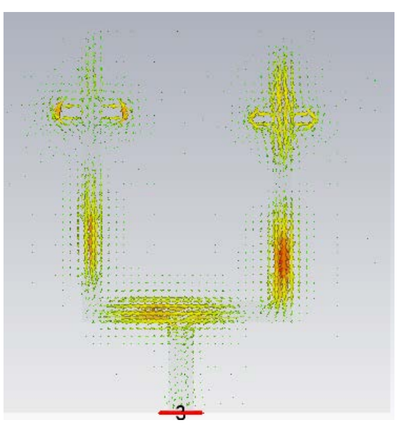


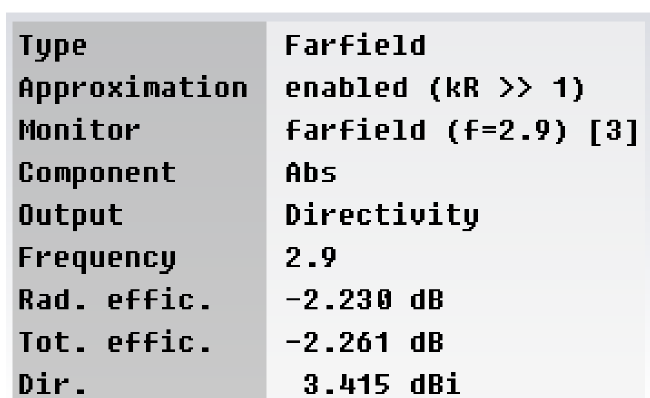


(a) (b)



(c)





Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=2.9) [3]
Component	Abs
Output	Directivity
Frequency	2.9
Rad. effic.	-2.230 dB
Tot. effic.	-2.261 dB
Dir.	3.415 dBi

(d) (e)

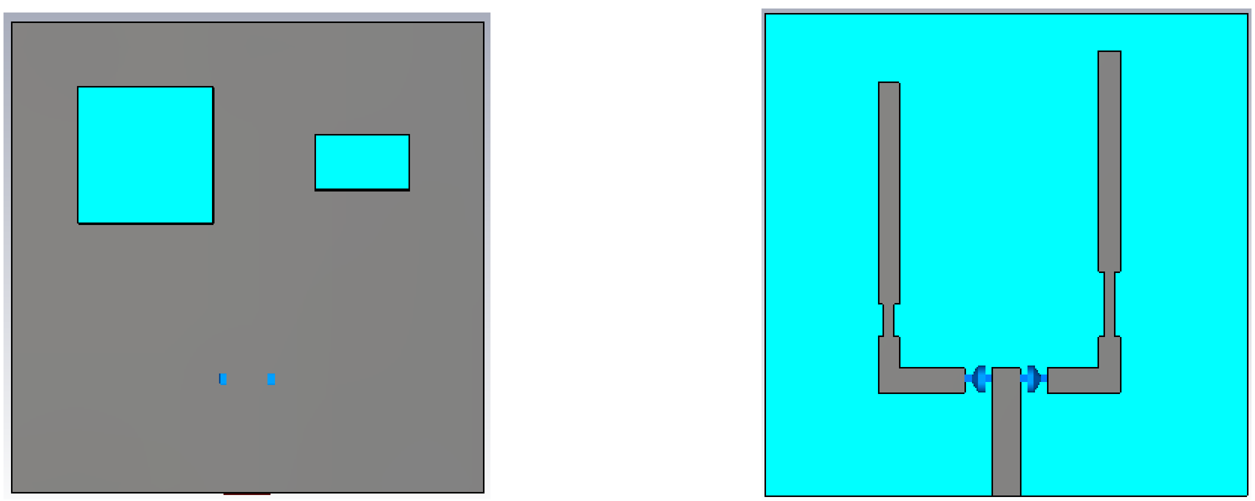
Figure 5.12 (a) E plane (b) H plane (c) Gain vs. frequency plot (d) Surface current plot (e) Efficiency value

The radiation pattern i.e. E plane and H plane are shown in the above figure. Both E plane and H plane have some major and minor lobes present, which shows that the antenna is radiating in some direction. From the gain plot, the realized gain of the antenna is found to be 1.6 dBi and it is maximum at the resonant frequency. The directivity of the antenna is 3.415 dBi and the radiation efficiency is 78%.

Design 4

5.2.4 Reconfiguring the above antenna

The above antenna can be made frequency reconfigurable by using two PIN diodes in the feed network as shown below.



(a) (b)

Figure 5.13 (a) Front view (b) Rear view of the reconfigurable antenna

As design 3 here also we are getting three operating conditions by switching the diodes. The PIN diodes can be switched on or off by making them forward biased or reverse biased respectively. The geometry of the antenna is same as the antenna discussed in 6.2.3. All the parameters are optimized using a parametric study in which the length and width of the aperture slot are varied to obtain different results. The antenna can be used for different applications like WLAN, IMTS, and WIMAX etc. All the simulated result are shown in the figure below.

5.2.4.1 Simulation results

Using PIN diodes we obtain three different states, i.e. ON-OFF, OFF-ON and ON-ON. All the results are obtained for these 3 operating modes separately.

<u>When the left diode is ON, i.e. in ON-OFF</u>

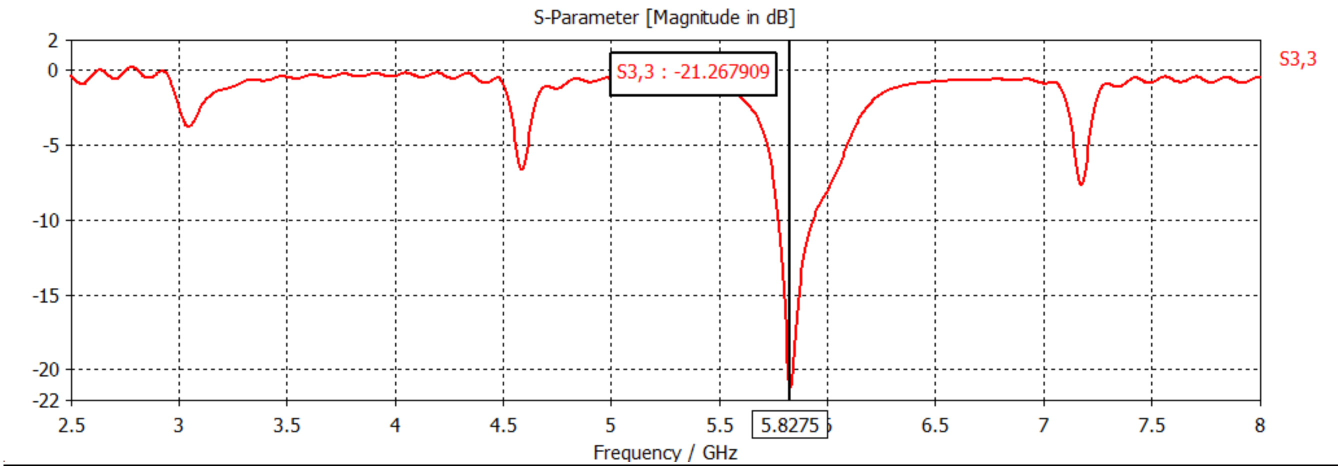


Figure 5.14 Return loss vs. frequency plot in ON OFF

By keeping only one diode ON, we are allowing current in only one direction. So the left dielectric resonator will be excited. In this state a narrow band of frequency 5.82 GHz is obtained as shown in the above figure. This can be used for WLAN applications. The return loss value is less than -20 dB, which shows that very less reflection is occurring. The impedance bandwidth is calculated as 10%.

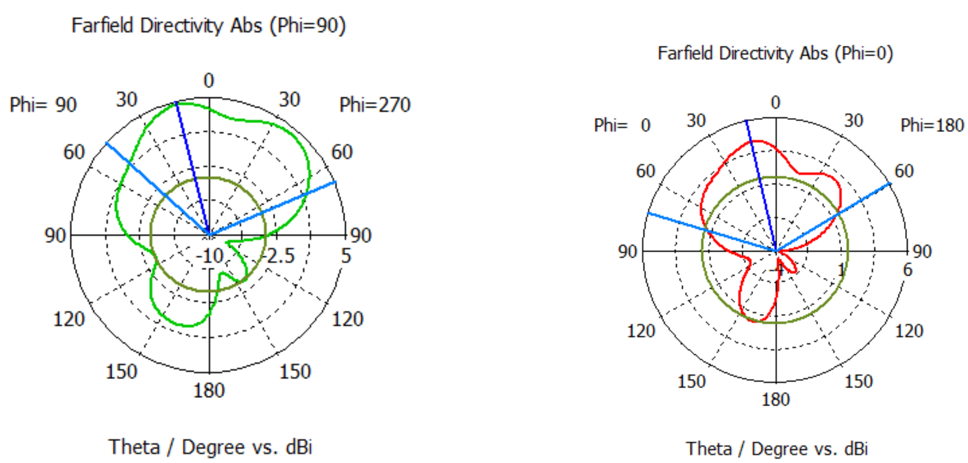
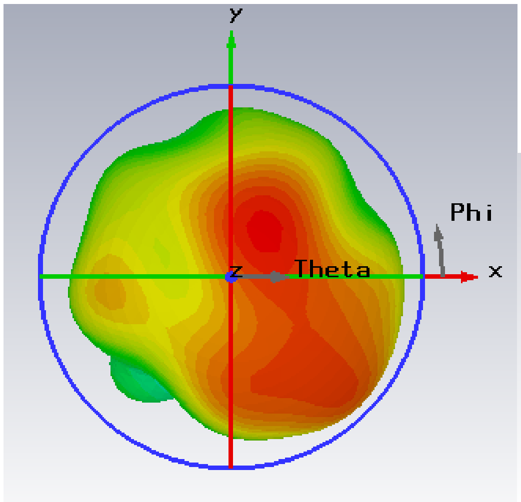


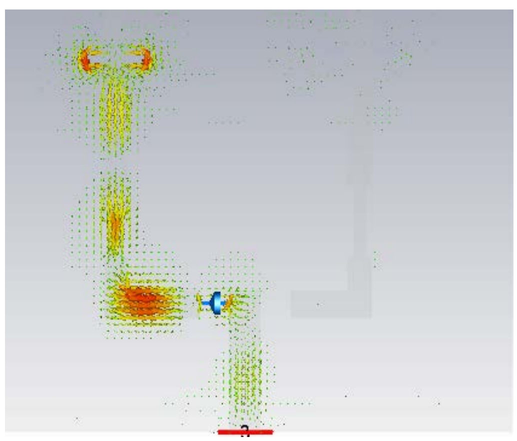
Figure 5.15 Radiation pattern (a) H plane (b) E plane

The E plane and H plane gives maximum value of electric field and magnetic field in a direction. From the figure it is shown that the antenna is omnidirectional, that means the antenna is radiating in all direction.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=5.8275) [3]
Component	Abs
Output	Realized Gain
Frequency	5.8275
Rad. effic.	-0.1048 dB
Tot. effic.	-0.1373 dB
rlzd.Gain	4.604 dB

(a) (b)



(c)

Figure 5.16 (a) 3D plot (b) Realized gain (c) Surface current distribution in ON OFF

From the above figure the realized gain is found to be 4.604 dB and the efficiency of the antenna is 98%. The surface current plot shows the direction of current in the antenna and the part where maximum radiation occurs.

When right diode is ON, i.e. in OFF ON

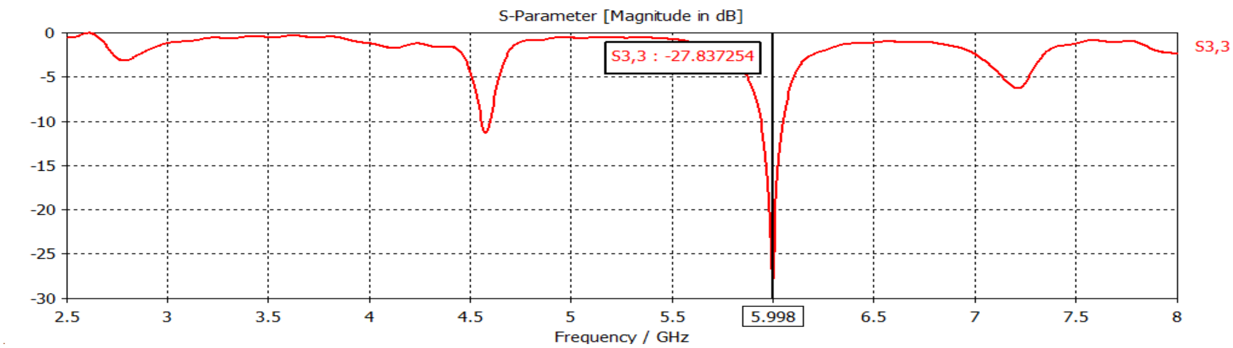
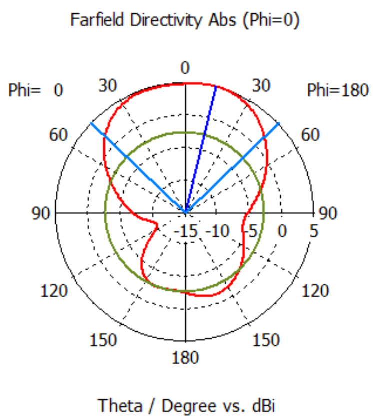
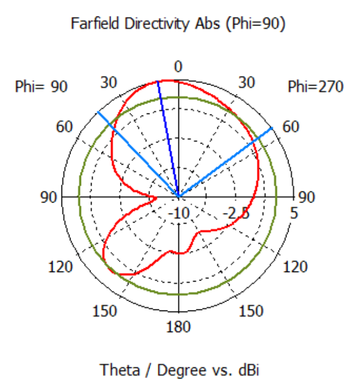


Figure 5.17 Return loss vs. frequency plot in OFF ON

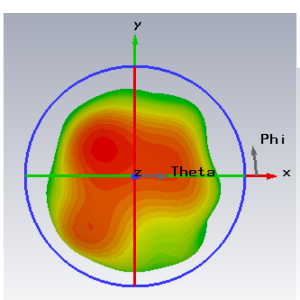
From the above figure it can be seen that in OFF ON mode a dual band with 2 center frequencies 4.6 GHz and 5.998 GHz is obtained. The return loss value at 5.998 GHz is -27.83 dB.



(a)



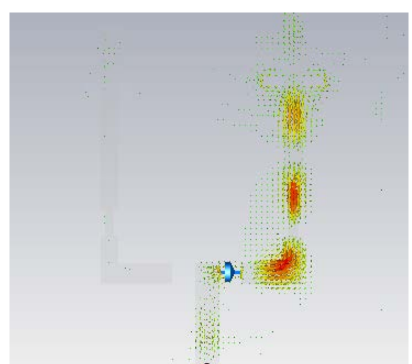
(b)



(c)

Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=5.998) [3]
Component	Abs
Output	Realized Gain
Frequency	5.998
Rad. effic.	-0.2064 dB
Tot. effic.	-0.2135 dB
rlzd.Gain	5.164 dB

(d)

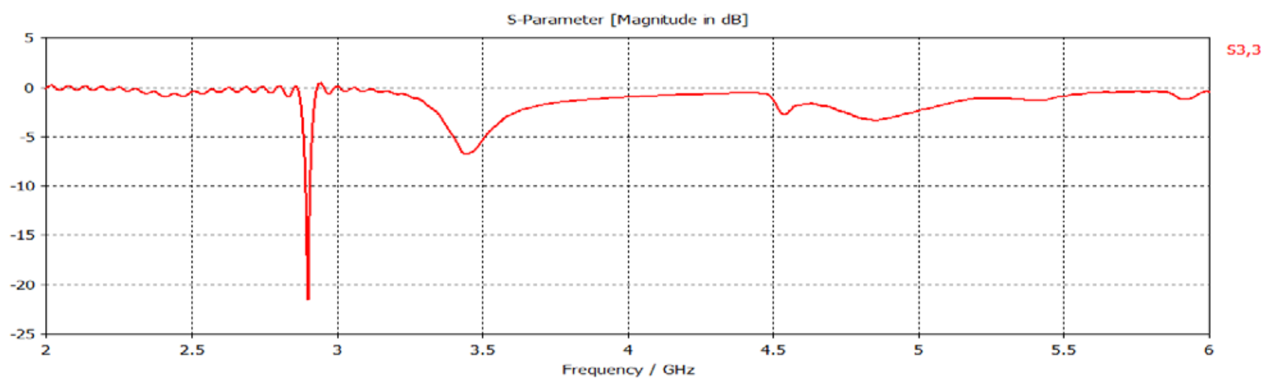


(e)

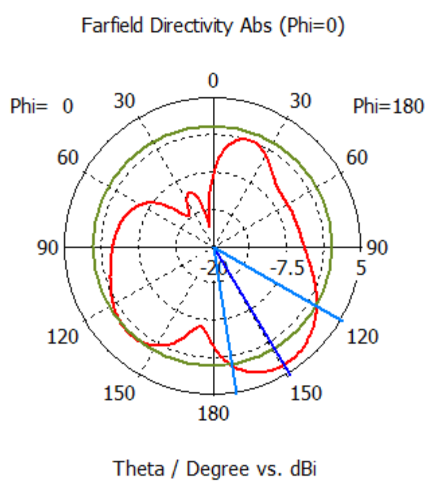
Figure 5.18 (a) E plane (b) H plane (c) 3D plot (d) Realized gain (e) Surface current plot

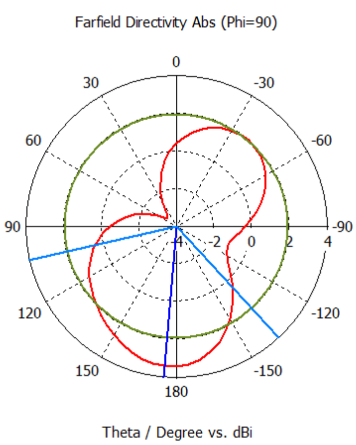
When both the diodes are ON, i.e. ON ON

In this condition we are getting the same results as discussed earlier i.e. a single band frequency at 2.9 GHz is obtained.

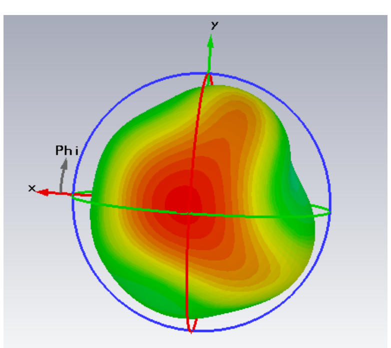


(a)





(b) (c)



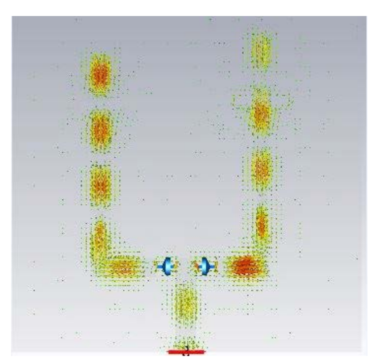


Figure 5.19 (a) Return loss plot (b) E plane (c) H plane (d) 3D plot (e) Surface current plot

5.2.4.2 Summary

Table 5.6 Different parameters at 3 different states (design 4)

Operating modes	Resonating frequency (GHz)	Gain (dBi)	Impedance Bandwidth	Radiation efficiency
OFF-ON	6	5.164	5%	98%
ON-OFF	5.8	4.604	11%	97%
ON-ON	2.9	1.823	4%	78%

Chapter 6

Conclusion and Future work

Conclusion

In this thesis 3 different frequency reconfigurable dielectric resonator antenna is presented and analyzed. These antennas can be used for various applications like WLAN operating in 2.7-3.1 GHz and 5.1-6 GHz, WIMAX operating in 3.3-3.7 GHz, international mobile telecommunication system (IMTS), and INSAT (Indian national satellite system) 4.5-4.8 GHz etc. The first antenna is designed by shorting the edge of DRA to the ground plane. 3 tabs are used to obtain six different unique operating modes. Here the shorting tabs act like ideal switches. All the parameters are optimized using CST studio suite 2012. The simulation results show the antenna use in different applications. The second and third antennas are designed by taking two dielectric resonators and reconfigurabillity is obtained by using PIN diodes. PIN diodes are considered because of their advantages like they are easily available, low cost, high switching speed etc. In the second antenna CPW feeding technique is used in which the ground plane is placed above the substrate. In the final design first the antenna is presented without PIN diodes and later PIN diodes are used to observe 3 different operating conditions.

Future work

- Different numerical techniques can be employed to design DRA.
- To design antennas which are both frequency and polarization or frequency and pattern reconfigurable.
- Fabrication and measurement of antennas will be done.

Publication

J.P. Das, N. Shrivastava, S.K. Behera, "Design of conjugate DRA with power divider for WLAN applications", Global conference on communication technology (GCCT 2015), IEEE, April 23-24, 2015

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