DESIGN AND OPTIMIZATION OF DIELECTRIC RESONATOR ANTENNA ARRAY FOR C-BAND SATELLITE APPLICATIONS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Electrical Engineering

BY

Saurav Gupta

Roll .No- 212EE1206

DEPARTMENT OF ELECTRICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA-769008,

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CERTIFICATE

This is to certify that the thesis entitled, **"DESIGN AND OPTIMIZATION OF DIELECTRIC RESONATOR ANTENNA ARRAY FOR C-BAND SATELLITE APPLICATIONS"** submitted by **Mr. Saurav Gupta** in partial fulfilment of the requirements for the award of Master of Technology Degree in **ELECTRICAL ENGINEERING** with specialization in **"ELECTRONICS SYSTEM AND COMMUNICATION"** at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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Abstract

The increasing use of wireless and satellite communication systems demand the antennas for different systems and standards with properties like reduced size, broadband, multiband operation, moderate gain etc. The planar and dielectric resonator antennas are the present day antenna designer's choice. However, conducting microstrip patch antennas inherently have a narrow bandwidth. In this thesis, a low-cost compact Dielectric Resonator Antenna array resulting Wideband characteristics with a band dispensation is presented. The antenna is implemented on FR4 substrate with a thickness of 1.6 mm and relative permittivity (ε_r) of 4.4. It has a partial ground plane. The antenna array is fed by the rectangular conformal patch attached to microstrip line. The reflection coefficient (S_{11}) is less than -10 dB in 5.4 GHz−7.4 GHz frequency range with possible satellite applications. The array factor consideration for Rectangular Dielectric Resonator Antenna is also been analysed in this thesis. The proposed antenna array is then optimized using genetic optimization technique to reduce the side lobe level and at the same time to increase the directive gain of the antenna. The performance characteristics of the proposed antenna are simulated using CST microwave studio 2011^{TM} software. The performance characteristics that have been analysed using CST microwave studio 2011^{TM} software are Return loss (S_{11}), Voltage Standing Wave Ratio (VSWR) and Farfield radiation pattern plot. The 'Roger' dielectric material is used for resonator having dielectric constant (ε_r=10.1). The dielectric material 'Teflon' can also be introduces in place of roger as rogger is not easily available. The thesis contains MATLAB generated plots showing the optimization using the concept of genetic algorithm.

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ABBREVIATIONS USED

UWB	Ultra-wide band
WLAN	Wireless Local Area Network
VSWR	Voltage standing wave ratio
DRA	Dielectric resonator antenna
RP	Rectangular Conformal Patch
HPBW	Half Power Beam Width

Chapter-1

INTRODUCTION

1.1 Introduction

Wireless and Satellite communication was spreaded all over the world at a very good speed in the last few decades, which provides greater flexibility in the communication sector of surroundings like in hospital, several factories, and many office buildings [1], [2]. The IEEE c-band (4-8 GHz) and its slight variations contains frequency ranges that are used for many satellite communication transmission. The microwave frequency of the C-band performs better under adverse weather condition compared to other bands. WiMAX and WLAN are the standard-based technologies those enable delivering the last mile wireless broadband access [3]. WiMAX is referred to as interoperably implemented IEEE 802.16 wireless-network standard that operates at higher bit rates over greater distance. It has the capability to operate in 3.4-3.6 GHz frequency ranges and at 5.5 GHz band [4] too. Whereas recently WLAN standard, those lies within the range of 2.4-GHz is emerged in market. And the data rates supported by this type of system are limited up to few Mbps. On the contrast, a no. of standards that had defined in the range of 5-6 GHz allow the data rates higher than 20 Megabits per second, which offers better solution for real-time imaging, multimedia, and high-speed video applications. But for achieving all the necessary applications a high performance wide band antenna is needed including best ever radiation characteristics [1]. During the last few decades, dielectric resonator antennas are widely accepted for several advantages i.e.

- low dissipation loss
- higher power handling capacity
- low profile
- high dielectric strength
- light weight [2] [5] [7]

DRAs are of several types. Such as

- Cylindrical DRA,
- Rectangular DRA,
- Spherical DRA,
- Half-split cylindrical DRA,

- disk DRA,
- hemispherical DRA
- Triangular shaped DRA [8].

In the last 2 decades, two categories of novel antennas had been studied and extensively reported on, one is microstrip patch antenna and the other one is the DRA. They both are very much appropriate for developing latest wireless communications. The main purpose of design any antenna is to obtain a wide range of bandwidth. Many techniques were reported on the modified feed geometry to enhance the bandwidth and to change the shape of dielectric resonator antennas. Using several bandwidth enhancement techniques in this thesis different shape of dielectric resonator antennas are designed and simulated. There is few software available which allow the optimization of these antennas. Here the method of simulation is done by using Computer Simulation Technology 2011^{TM}. In this thesis, there have been designed different shapes of single and multiple dielectric resonator antennas for wireless applications. Bandwidth enhancement techniques are used to obtain a large bandwidth for particular resonant frequencies.

1.2. Motivation to the work:-

The main motivation of this thesis is that, the use of wireless mobile communication systems and the use of satellite communication systems is increasing and becoming popular day by day, which demands antenna to be used for different systems and for standards with several characteristics like reduction in size, multiband operation, broadband, moderate gain etc. To be very flexible enough to have possible future mobile communication frequency bands, “Antenna” work on the basis of software-defined system requires ultra wide band characteristics. One approach for providing this type of flexibility is to prepare a multi band antenna which will operate on certain narrowband frequencies. Still it will be very tough to exactly acquire all the frequency requirement of every future’s communication system. Again, small wideband antennas which cover wide range of frequency will be a great candidate, both for multi-band applications and future communication system that operates over each latest frequency band. Now a days, it is explained that a wideband monopole antenna is better to use in case of mobile wireless devices e.g. computer, notebooks, mobile phones, and personal digital assistance. Wide band applications using conventional Microstrip patch designs and dielectric resonator antenna (DRA) designs are limited, which has bandwidths as low as a few percent. Some other drawbacks those the patch antennas include are low efficiency, limited power capacity, spurious feed radiation, narrow bandwidth, poor polarization and manufacturing tolerance problems.

To increase the bandwidth and low frequency ratio of a patch antenna and dielectric resonator antenna (DRA), Research scientists have developed several methods just to overcome these problems for about two decades. The motivation here to extend the dielectric resonator antenna used for wireless communication is due to the dimension of the DRA is of the order $\lambda_0/\sqrt{\varepsilon_r}$ where λ_0 is the free space wavelength and ε_r is the dielectric constant of the resonator material. So it can be concluded that, choosing a high value of ε_r (5-100) will lead to the reduction of the size of DRA significantly. There is no conducting loss as there is no conductor in dielectric resonator antenna, which governs high radiation efficiency of DRA. Mainly in every millimeter wave antenna, this feature is very much attractive, in which there is heavy loss in metal fabricated antennas. Many of these techniques involve adjustment of the placement and type of element used to feed or excite the antenna. Now a day, for many applications this wide band frequency operation of antennas became highly necessary. However for most of the applications Microstrip antennas and DRAs are ultimately expected to replace conventional antennas.

To increase the bandwidth and to obtain dual band response for an antenna Research scientists have developed several techniques in recent few decades. Many of those techniques involve adjustment of the dimensions of ground or substrate material, using dielectric constant of material, more number of DRAs, or different type of feed or excite the antenna.

Recently the experience of economic growth in the field of wireless communication industry, mainly in case of wireless data communication and cellular telephony, has led to increase in demand for the multi-band antennas.

Several requirements which will be needed for the digital home are:

- Satellite communication system
- Location and Tracking
- Radar and Imaging
- Medical Applications

- high-speed data transfer for multimedia
- content, short-range connectivity for transfer to other devices

1.3 Literature Review and Objective:-

In 1939, Richtinger theoretically demonstrated the microwave resonators in the form of unmetalized dielectric spheres and triodes [1]. However in 1960s more investigation and analysis was done by Okaya and Barash. Though open DRs are found to radiate some years back, but the use of DRs as antenna concept was still not being accepted over a wide range until original papers about cylindrical dielectric resonator antenna (DRA) were published in 1983.

After the cylindrical DRA had been studied, Long and his colleagues subsequently investigated the rectangular and hemispherical DRAs. In the mid-1990s more study concentrate on linear and planar DRA array from simple two-element arrays to complex phased arrays. This job has developed the foundation to investigate about DRA in future and its applications have been receiving enormous attention in recent years. This is generally found out that the frequency range of interest for so many systems gradually progressed upward to millimeter or near-millimeter range of (200-400 GHz). With this frequency, the conductor loss of metallic antennas becomes very severe and efficiency of antennas is reduced gradually. On the other hand, the DRA loss is due to imperfect dielectric material present in it, practically it is very small in amount. Dielectric Resonator Antennas (DRA‘s) have become popular in recent years because of many advantages they offer like smaller size, ease of fabrication; greater radiation efficiencies, increased bandwidth and lesser production cost, which manifests DRA in different types of Wireless applications. The main objective of this thesis is to introduce a technique to enhance the bandwidth and to reduce the side lobe level using optimization technique; this also decreases the return loss and VSWR.

Second most important work objective in this thesis is to design and optimization of DRA array for high frequency applications in C-band. All simulation results are obtained by using one simple method Computer Simulation Technology (CST). It is one of the widely accepted high performance software which simulates electromagnetic fields in every frequency bands. This technique works to implement unique and growing edge technology in a user friendly manner. This can also be useful in industries as well as telecommunications, defense, automotive equipment, electronics and medical equipment. Computer Simulation Technology microwave studio 2011 is a specialized tool for the 3D Electro Magnetic simulation which is made up of high frequency elements. In leading Research & Development departments, CST microwave studio2011 is the first choice for technologies due to its unparalleled performance. These technologies enable the rapid and exact analysis of high frequency devices such as antennas, filters, couplers, planar and multi-layer structures. Especially the user friendly CST easily gives an intuitive understanding of the truth about the EM performance of high frequency designs. CST also provides more flexibility to deal with the difficulties of wide application range, through varieties of available technologies. CST MWS 2011 also provides solver modules for some specific applications. Therefore CST MWS 2011 is fixed firmly in several industry standard workflows through CST design environment.

1.4. Thesis Outline:-

The dissertation is divided into six chapters and the outline of the thesis is as follows:

Chapter 1:-In this chapter thesis overview is expressed. The thesis motivation and the literature review for the project has been done. Introduction for the applications of wireless and satellite communication has been shown. Introduction about the software used for the antenna design is shown.

Chapter 2:-It presents the basic theory of DRAs, including thecharacteristics of theDRA and the advantages, Comparison to microstrip antennas, different feeding methods (coaxial feed, slot aperture, microstrip line feed, co-planar feed, dielectric image guide), finally The basic DRA shapes with different parameters as presented in this chapter.

Chapter3:-In this chapter, study of linear antenna array and its array factor has been demonstrated. Controlling factors of array antenna is presented. Array factor consideration for DRA array has been analyzed. This chapter mainly describes the design of DRA array, simulation and result discussions. Validation of the algorithm.

[1]Design of Rectangular Dielectric Resonator antenna (DRA) array for satellite applications:[Roger (ε_r=10.1) as DR Element].

Simulation results obtained using the Computer simulation technology (CST),the simulation results (return loss, VSWR, directivity, etc.) has been analysed.

Chapter 4:-This chapter contains conclusion and suggestions for future work.

Chapter 2

Dielectric Resonator Antenna (DRA)

2.1 Introduction

Wireless communication has spreaded all over the world with a greater speed during the last decade, this provides greater flexibility in communication systems [8]. Both the Microstrip antenna and dielectric resonator antenna are very much popular and adoptable. While comparing between microstrip antenna and DRA, DRAs have much wider impedance bandwidth along with greater efficiency. Now a days these DRAs are used everywhere in electronic warfare, missile, radar and communication infrastructures. Both of them have several contributions towards military as well as commercial applications. DRAs are derived from dielectric resonator, based on varieties of excited feeding techniques [11].

Dielectric resonator (DR) first found during 1939.it is found out by Richtinger, a researcher of Stanford University, who demonstrated the theory that unmetallized dielectric objects in the form of triodes could function similarly as that of microwave resonators [9]. But his theoretical investigation was unable to generate suitable ideas, after that practically no significant information has been developed over 20-30 years. Earlier in 1960s, Okaya and Barash from Columbia University, reported the DR for the first time in the form of a single crystal TiO2 [10]. Dielectric resonator was first popular in the form of filter element devices used in microwave circuits. For the first time it is used as radiating elements up to 1980's until the smaller size potential as well as high frequency application agonized this research into dielectric resonator antenna [1-2].

2.2 Basic Characteristics

Dielectric resonator antennas (DRA) contain several significant characteristics those instigate the DRAs to show signs of future success, particularly in case of millimeter wave applications. Some properties of DRA like higher-radiation efficiency, bandwidth as well as polarization flexibility has made them far better than conventional microstrip patch antennas (MPA). DRA forms parts of basic nature which does not affect to surface wave power leakage as well as conductor loss problem; that plagues MPA and leads to decrement of efficiency. DRA materials are of heavy dielectric constant, which possess one peculiar property i.e. better quality factors and mounted on a grounded dielectric substrate with lower permittivity. DRAs are made up of low-loss, high relative dielectric constant materials of different shapes, and its resonant frequency is function of the size, shape and permittivity of that material. DRAs are of different types depending upon their shapes, such as rectangular, spherical, cylindrical, half-split cylindrical, disk, and hemispherical DRA [1]. DRAs have properties such as low phase noise, compact size, frequency stability as per temperature, ease of integration with several MIC circuits, easy method of construction with the ability to face against odd environment. The DRAs have several useful characteristics, like smaller size, ease of fabrication, high radiation efficiency, large bandwidth and less production cost. DRA is useful in wireless communication applications [2], [7].

DRA offers some useful properties which include:-

- Wider range of dielectric constants that we can use (ε_r= 10 – 100), which offers the designer making control over the size of DRA along with its bandwidth.
- However, size of DRA is directly proportional to $\boldsymbol{\lambda_0}$ /$\sqrt{\varepsilon_r}$ in which λ_0 is the free space wavelength at resonant frequency, and ε_r is dielectric constant of material.
- Size of DRA is also proportional to $\lambda_0/\sqrt{\varepsilon_r}$, in which λ_0 is the free space wavelength at the resonant frequency, and ε_r is the dielectric constant of that material.
- Sometimes DRA is constructed to operate on a larger frequency range i.e. from 1.3 GHz to 40 GHz [1].
- It gives a great radiation efficiency (somehow 95%) because of absence of conductor loss and surface wave loss.
- Some feeding mechanisms may be used (which includes slots, probes, microstrip lines, dielectric image guide, and coplanar waveguide lines) to fully excite the DRA.
- DRA can be excited by several modes; some of them radiate pattern same as that of short electric and magnetic dipoles, which produces either broadside or Omni- directional radiation pattern for various coverage requirement of DRA [2].
- While we select a dielectric material with lesser-loss characteristics, high-radiation efficiency is maintained at millimeter-wave frequency. This is due to lack of surface waves as well as lesser conductor losses of DRAs [1], [2].
- Makes control over its size as well as bandwidth
- Greater tolerance: ± 1- 5%,

- Better quality factor Q: up to 10000 (f = 10GHz)
- Higher temperature coefficient of resonance frequency: (-12…+30) ppm/ ^{o}C
- High tolerance ± 0.5; ±1.0; ±2.0 ppm/^{o}C

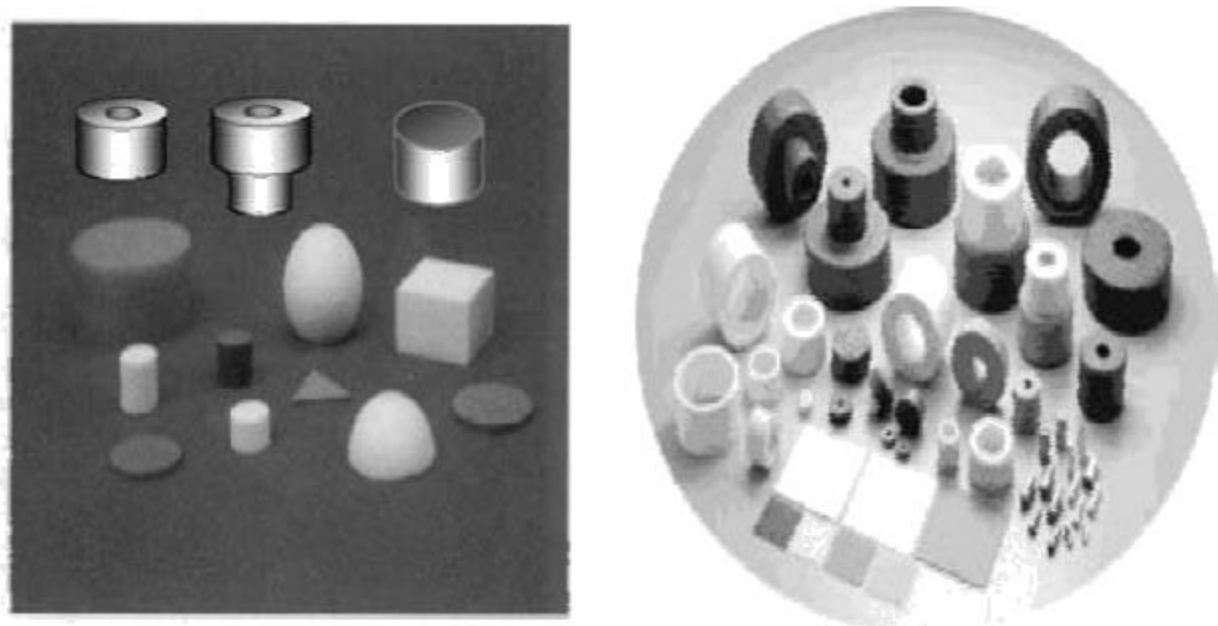


Figure 2.1 DRAs of various shapes (cylindrical, rectangular, hemispherical, low-profile circular-disk, low-profile triangular) [1].

2.3 Advantages:

In the past few years, extensive studies on the DRA have been focused on resonators of various shapes, the feeding techniques, and bandwidth enhancement methods. Specific features of DRAs has made them suitable for a variety of applications specially millimeter wave (MMW) applications. DRAs can be easily coupled to almost all types of transmission lines. They can be integrated easily with MMIC circuits. In MMW applications conductor loss of metallic antennas become severe and the antenna efficiency decreases significantly, conversely the only loss for a DRA is that due to the imperfect material of the DRA which can be very small in practice. Therefore DRAs have high radiation efficiency. In comparison to microstrip antennas, DRAs have wider impedance bandwidths. For a typical DRA with dielectric constant of 10 the impedance bandwidth of 10% can be achieved. Avoidance of surface waves is another attractive advantage of DRAs over microstrip antennas. Single DRAs of different shapes has been possible, including rectangular, cylindrical, hemispherical, triangular, conical, etc. Among these different shapes cylindrical and rectangular are the most common and the rectangular has the advantage of having one more degree of freedom for design purposes. There are a variety of feed configurations, which electromagnetic fields can be coupled to DRAs [5]. Most common feed arrangements are microstrip aperture coupling, direct microstrip coupling, probe coupling and conformal strip coupling. Among these feed configurations, aperture coupling is more suitable for MMW applications. In aperture coupling configuration, since the DRA is placed on the ground plane of the microstrip feed, parasitic radiation from the microstrip line is avoided. Isolation of the feed network from the radiating element is another advantage of the aperture coupling method [1], [2], [7]. Dielectric resonator antennas (DRAs) have been extensively used for numerous applications since they have many attractive characteristics such as low profile, light weight, low cost, and inherently wide bandwidth. They could be used for numerous applications as both individual elements and in an array environment. In addition, wide bandwidth, low cost, low dissipation loss at high frequency, and high radiation efficiency are the inherent advantages of DRAs over conventional patch antennas. Compared with Microstrip antennas, which suffer from higher conduction loss and surface waves in antenna array applications, DRAs have high radiation efficiency and high power handling capability due to lack of metallic loss. Unlike the microstrip antenna, DRA does not support surface waves if placed on a ground plane directly [13], [7]. In recent years, DRAs have been considered as potential antennas for mobile phone applications. A general problem in the miniaturization of RF resonators used in filters and small antennas is decrease of efficiency, due to conductor losses. In DRAs, lower conductor losses, compared to those in typical metal antennas such as microstrip patches can be expected because DRAs have fewer metal parts. Thus, DRAs are good potential alternatives, especially when very small antenna elements are needed. In addition, they can be easily incorporated into microwave integrated circuits because they can be fabricated directly on the printed circuit board (PCB) of the phone. Specific features of DRAs have made them suitable for a variety of applications specially MMW applications. DRAs have small size and low cost. They can be easily coupled to almost all types of transmission lines [19], [20]. Dielectric resonator antennas have several advantages compared to conventional microwave antennas, and therefore many applications cover the broad frequency range. Some of the principal advantages of dielectric resonator antennas compared to conventional microstrip antennas are [6]:

- DRA has a much wider impendence bandwidth as compared to microstrip antenna because it is radiated through the whole antenna surface excluding the ground port while microstrip antenna, which radiate only through two narrow radiation slots.
- More efficiency
- Avoiding surface waves is another principal advantage of DRAs as compared to microstrip antennas
- However, dielectric resonator antennas too have some advantages:
- Lighter in weight, less volume, and low profile configuration, which is made conventional;
- DRA has higher degree of flexibility or versatility, which allows the designs to be suitable for a wider range of physical or electrical requirements of various communication applications.
- Ease of fabrication
- High radiation efficiency
- High dielectric strength and large power handling capacity
- In DRA, different shapes of resonators can be used (i.e. rectangular, cylindrical, hemispherical, etc.) that allow flexibility in design.
- Low production cost
- So many feeding mechanisms will be used (such as probes, slots, microstrip lines, dielectric image guides, and coplanar waveguide lines). These are used effectively to excite DRAs, and make them cooperative to integrate with different existing technologies [1], [2], [5] - [7].

2.4 Feeding Method:

Various techniques those are available for feeding or transmitting electromagnetic energy to dielectric resonator antennas. The five principal feeding methods are the coaxial probe, slot aperture, microstrip line, co-planar coupling and dielectric image guide [1], [21].

2.4.1 Coaxial Feed:

This is also known as probe feed, it is a very simple technique generally used to feed dielectric resonator antennas as shown in figure 2.2. In this method, the probe can either be placed adjacent to DRA or can be fixed firmly with its surrounding mass. The amount of coupling between the DRA and the probe can be enhanced by adjusting the probe height and DRA location. In DRA, numerous types of modes can be excited, which depends upon the location of the probe. In the probe which is located adjacent to the DRA, the magnetic fields of the $TE_{11\delta}$ mode of the rectangular DRA, is excited and radiate like horizontal magnetic dipole. In case of a probe located in the middle of a cylindrical DRA, the TE_{011} mode is excited and radiate like a vertical dipole. Another benefit of using probe coupling is that one can couple directly into a 50Ω system, without the requirement of a matching network. Probes are suitable at lower frequencies in which aperture coupling may not be applied because of the requirement of larger size of the slot [2].

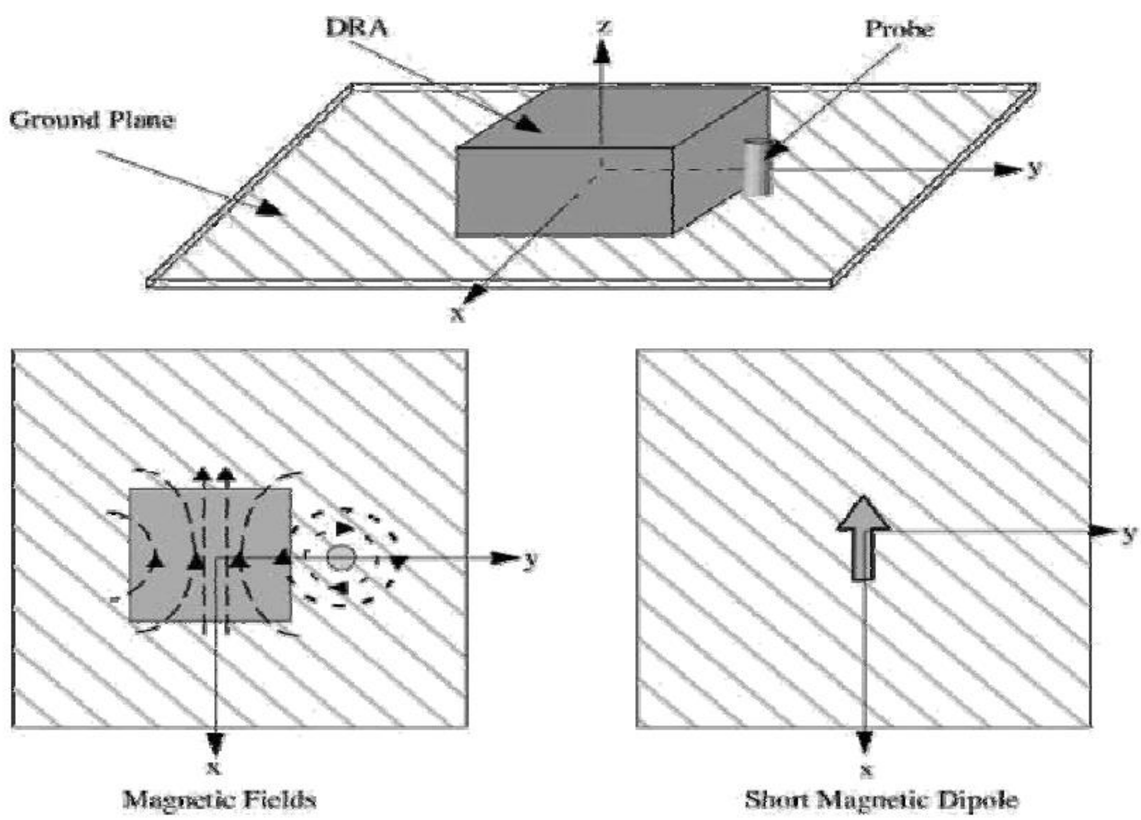


Figure 2.2 Probe-fed Dielectric resonator antennas [1].

2.4.2 Slot Aperture:

In slot aperture method, excitement of DRAs is done through an aperture in the ground plane on which it is located. Aperture coupling is applied to DRAs of any shapes such as rectangular, cylindrical or hemispherical. The aperture works similar to a magnetic current flowing parallel to the size of the slot that excites the magnetic field present in the DRA. This aperture consists of a slot cut in a ground plane which is fed by microstrip line located below the ground plane. For avoiding spurious radiation, feed network is located below the ground plane. Moreover, slot coupling is a great technique to integrate DRAs with printed feed structures. The coupling level may be changed by moving DRA with respect to the slot. Normally, a higher dielectric material is used for the substrate and a thicker, less dielectric constant material is used for the top dielectric resonator patch for optimization radiation of the antenna [1]. The main drawback of the feeding technique is that it is very tedious task to fabricate because of the presence of multiple layers, as the thickness of antenna increases bandwidth (up to 21%) [2].

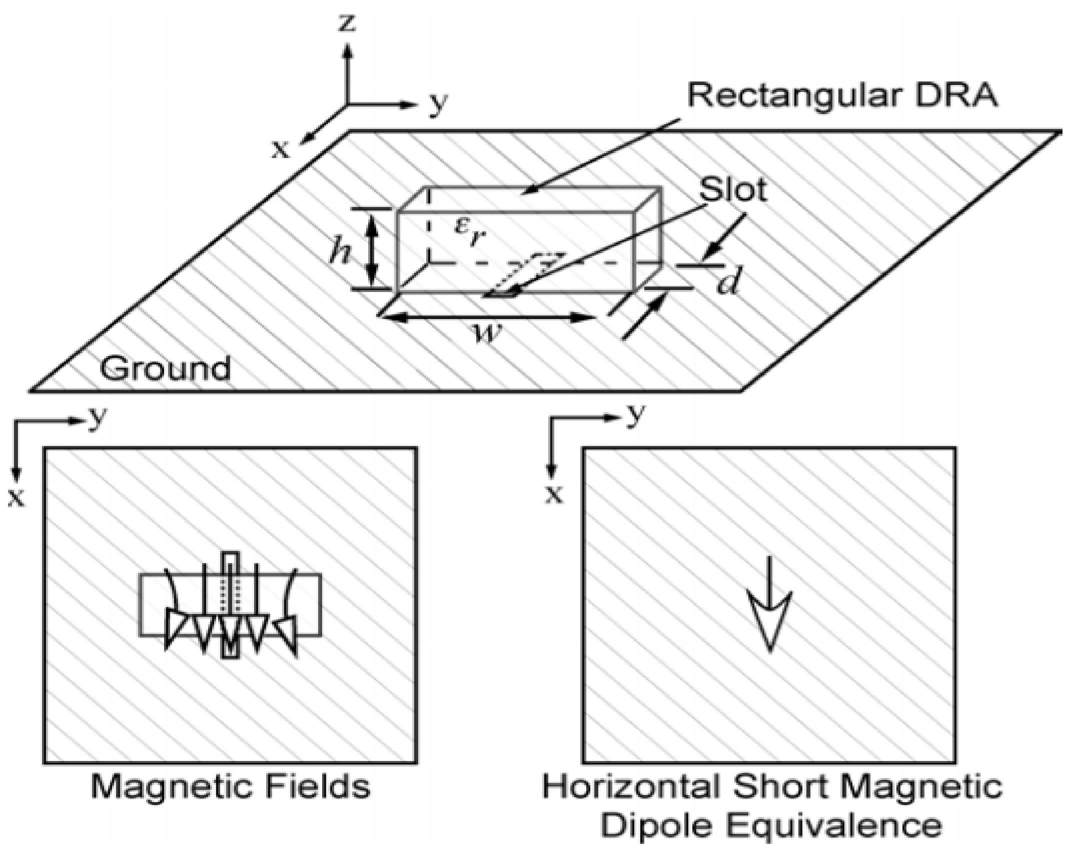


Figure 2.3 Aperture-fed Dielectric resonator antenna [1].

2.4.3 Microstrip Line Feed:

There is a conducting strip which is attached directly with the edges of the patch in this kind of feeding technique as shown in figure 2.4. General methods of coupling to dielectric resonators in microwave circuits are done by proximity coupling to microstrip lines. Microstrip coupling excites the magnetic fields in DRA to create a mode of short horizontal magnetic dipole. The level of coupling will be changed by lateral location of DRA with respect to microstrip line or on the relative permittivity of DRA [2]. In DRAs, the extent of coupling is normally very small for the requiring wide bandwidth. Microstrip lines may be used as a series fed linear array for DRAs. This is quite easier feeding technique, because it offers ease of fabrication and simple modeling along with impedance matching.

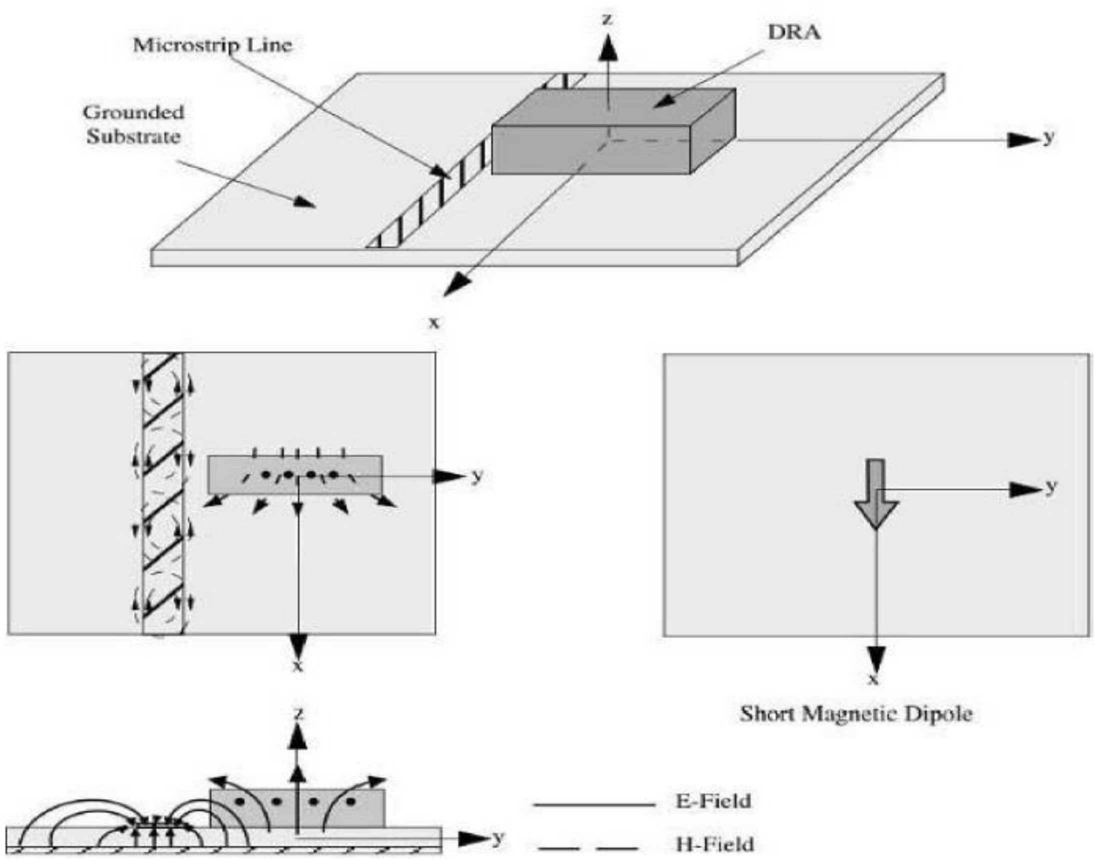


Figure 2.4 Microstrip-fed DRA [1].

The thickness of the dielectric substrate being used increases, at the same time surface waves along with spurious feed radiation also rises that affects the bandwidth of antenna [1]. One drawback of this process is that the polarization of array is analyzed by the orientation of microstrip lines such as the direction of the magnetic fields in the DRA will be parallel to the microstrip line [1], [2].

2.4.4 Co-Planar Feed:

The Co- planar feed is another common method used for coupling in dielectric resonator antennas. Here, fig 2.5 shows a cylindrical DRA which is coupled with a co-planar loop. The coupling level will be adjusted by locating the DRA on the loop [2].

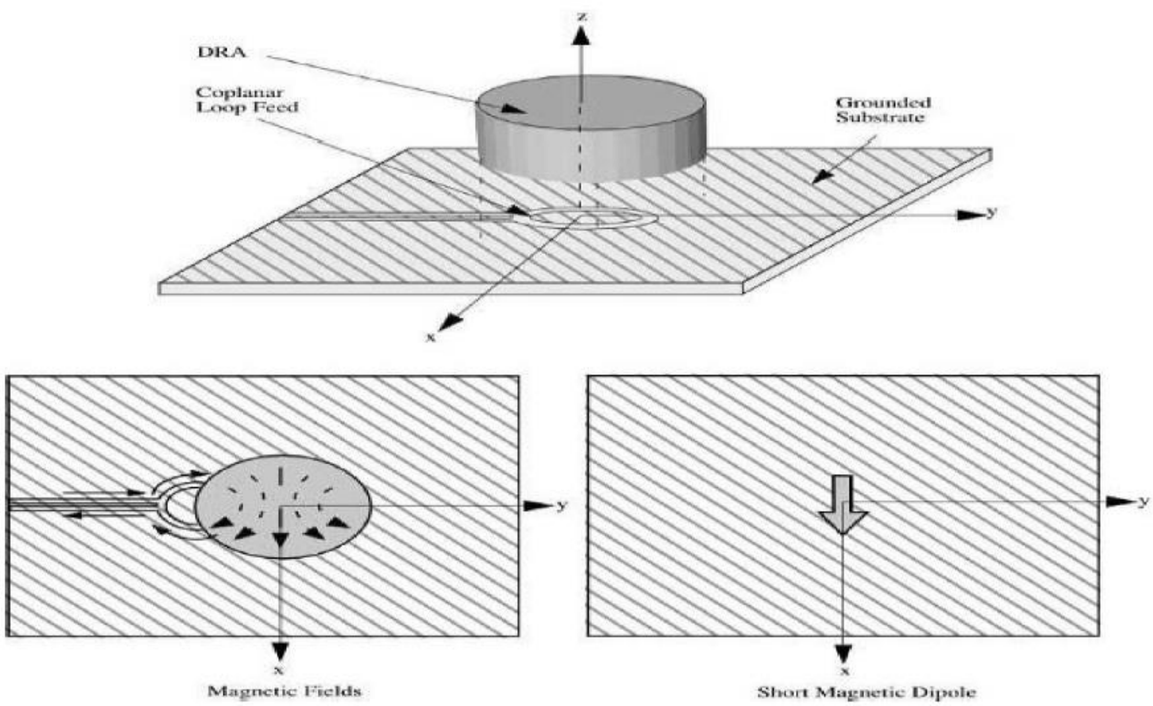


Figure 2.5 Co-planar loop-fed DRA [1].

The coupling behavior of the co-planar loop is exactly same as that of coaxial probe; however the loop offers some benefits as it is non-obtrusive. When we move the loop from the edge of

DRA towards central position, one may couple either into the $HE_{11\delta}$ mode or the TE_{011} mode of cylindrical DRA [1], [2].

2.4.5 Dielectric Image Guide:

Dielectric image guide is another attractive coupling technique in DRAs, shown in fig 2.6. Dielectric image guide offers several advantages compared to microstrip at millimeter-wave frequency, as they have not suffered seriously from conductor loss. Since in case of microstrip lines, the amount of coupling to DRA is normally very small, especially in DRAs having lower permittivity values, even it can be possible to enhance the amount of coupling by operating the guide nearer to cut-off frequencies. Hence the dielectric image guide is the best utilized series feed to any linear array present in a DRA [2].

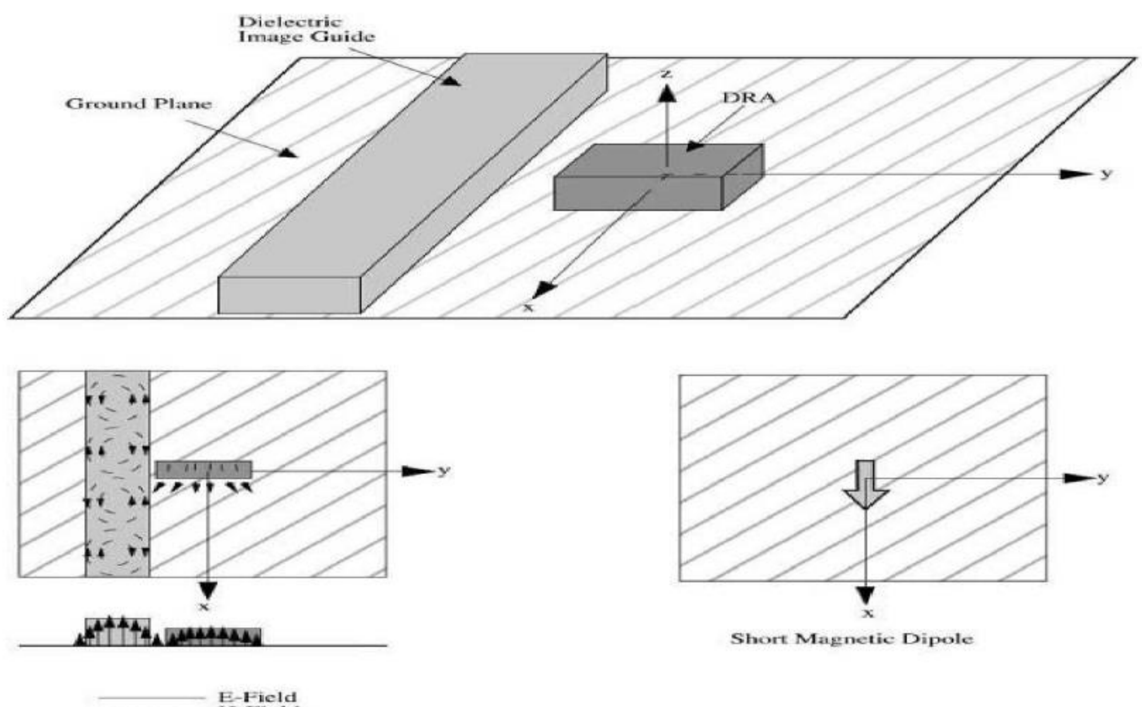


Figure *2.6 Dielectric image guide-fed DRA* [1].

2.5 Basic-shaped Dielectric resonator antenna:

Three basic shapes of the DRA as Cylindrical, rectangular and hemispherical are the most commonly used. Here, we studied about different shapes of DRAs and their different modes of configurations. This analysis is used for finding out the resonant frequency, radiation Q-factor, as well as the radiation pattern of DRA [1].

2.5.1 Cylindrical DRA:

Cylindrical DRA has advantages over hemispherical and rectangular shape DRA. It offers better design flexibility, where the ration of radius and height is controlled by the resonant frequency as well as the quality (Q) factor. If we vary the DRA dimension, various Q-factor can be obtained. In cylindrical DRA fabrication is much easier than hemispherical DRA and different modes can be easily excited. This results in broadside radiation pattern or omnidirectional radiation pattern. This gives one degree of freedom, that is greater than the hemispherical shape, it has aspect ratio a/h which determines Q factor for a specified dielectric constant .[1].

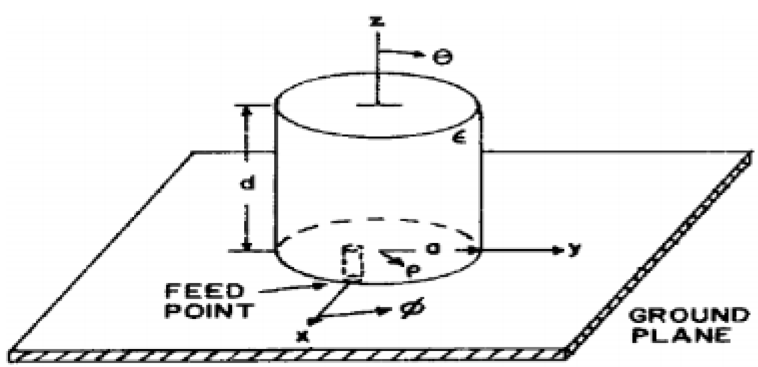


Fig.2.7 The geometry of cylindrical DRA [1].

Different subclasses of DRAs can be derived from cylindrical shape such as split-cylindrical DRA, cylindrical-ring DRA, electric monopole DRA, disk-loaded cylindrical DRA, sectored cylindrical and ring DRAs, elliptical DRA, conical DRAs. Ring DRAs are the subclass of the cylindrical DRAs, which offer higher impedance bandwidth performance. Cylindrical dielectric resonators are used in circuit applications, filters, and oscillators and especially in microstrip technology, where resonant waveguide cavities are not very practical. The geometry of cylindrical DRAs is shown in figure 2.7. It consists of a material with a height h, radius a, and dielectric constant (ε_r). This shape gives one degree of freedom more than that of hemispherical shape because it has aspect ratio a/h, which calculates k0a and the Q-factor for a given dielectric constant [1], [2].

2.5.1.1 Resonant frequencies:

In the analysis, the dielectric resonator antenna surfaces is perfect magnetic conductors, where wave functions which are transverse electric (TE) to z and transverse magnetic (TM) to z, hence we may write this as [2],

$$\psi_{TE_{nmp}} = J_n\left(\frac{X_{np}}{a}\rho\right)\begin{pmatrix}\sin n\phi \\ \cos n\phi\end{pmatrix}\sin\left[\frac{(2\mathrm{m}+1)\Pi \mathrm{z}}{2d}\right] \quad \textbf{(2.1)}$$

$$\psi_{TE_{nmp}} = J_n\left(\frac{X_{np}}{a}\rho\right)\begin{pmatrix}\sin n\phi \\ \cos n\phi\end{pmatrix}\cos\left[\frac{(2\mathrm{m}+1)\Pi \mathrm{z}}{2d}\right] \quad \textbf{(2.2)}$$

Where J_n = Bessel function of the first kind

Analyzed resonant frequency of the npm mode is:

$$f_{nmp} = \frac{1}{2\Pi a\sqrt{\mu\varepsilon}}\sqrt{\begin{pmatrix}X_{np}^2 \\ X_{np}^{'2}\end{pmatrix} + \left[\frac{\Pi a}{2d}(2\mathrm{m}+1)\right]^2} \quad \textbf{(2.3)}$$

For TM mode, calculated resonant frequency is given by:

$$f_{TM_{110}} = \frac{1}{2\Pi a\sqrt{\mu\varepsilon}}\sqrt{X_{11}^{'2} + \left(\frac{\Pi a}{2d}\right)^2} \quad \textbf{(2.4)}$$

Where X‘11 = 1.841

2.5.2 Hemispherical DRA:

Hemispherical shaped DRA offers several advantages as compared to rectangular and cylindrical shaped DRAs, since the interface between the dielectric and air is simpler in case of hemispherical shape. Hence a closed form expression is obtained for the Green's function.

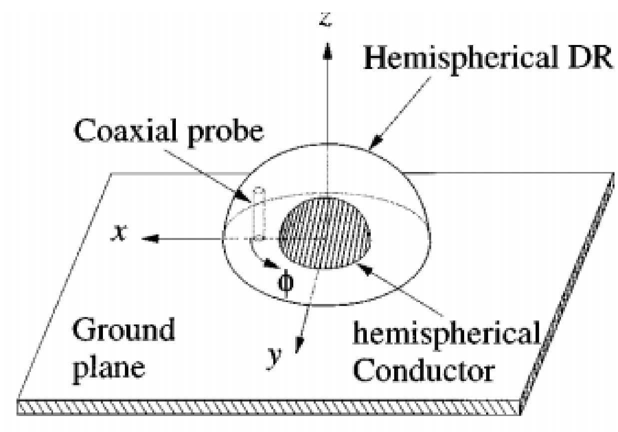


Figure 2.8 Configuration of a probe-fed hemispherical DRA

The hemispherical DRA is characterized by radius 'a', a dielectric constant ε_r as shown in figure2.8. Here, we assumed that the hemispherical DRA which is mounted over ground plane has infinite conductivity and infinite extent. Image theory is useful to equate the hemispherical DRA of radius ='a' to an isolated dielectric sphere having the same radius.

Transverse electric (TE) as well as transverse magnetic (TM) are different modes in dielectric sphere. Transverse electric (TE) modes, which have zero value for radial component of electric field (E_r=0), whereas transverse magnetic(TM) mode is having a zero radial component of magnetic field (H_r=0). The two fundamental modes for hemispherical DRA are TE_{111}, whose radiation pattern is same as that of short horizontal magnetic dipole and TM_{101}, whose radiation patterns are also same as that of short electric monopole.

2.5.2.1 TE_{111} mode approximation:

TE_{111} mode is the lowest order mode of the hemispherical DRA. This mode creates far-field radiation patterns same as short horizontal magnetic dipole. It has a wider beam along with a broadside peak. This resonant frequency as well as radiation quality (Q) factor for TE_{111} mode is determined by solving the characteristic equation [1]:

$$\frac{j_{1/2(\sqrt{\varepsilon_r}\,\mathrm{k_0 a})}}{j_{3/2(\sqrt{\varepsilon_r}\,\mathrm{k_0 a})}} = \frac{H^{(2)}_{1/2}(\mathrm{k_0 a})}{\sqrt{\varepsilon_r}\,H^{(2)}_{1/2}(\mathrm{k_0 a})} \qquad \textbf{(2.5)}$$

Where J(x) = first order Bessel function

$H^{(2)}(x)$ = Second order Henkel function

k0 = free space wave number

After obtaining k0 value, the resonant frequency can be determined:

$$f_{GH_z} = \frac{4.7713 R_e(\mathrm{k_0 a})}{a_{cm}} \qquad \textbf{(2.6)}$$

2.5.3 Rectangular DRA:

The rectangular shape DRA has more advantages over cylindrical and hemispherical shape DRA. It offers a second degree of freedom which is one more than cylindrical shape and two more than hemispherical shape. It provides designer to have a greater design flexibility to achieve the desired profile and bandwidth characteristics for a given resonant frequency and dielectric constant. In an isolated rectangular dielectric guide, the various modes are divided into TE and TM, but in DRAs, those are mounted on the ground plane only TE mode will be typically excited. The rectangular DRA will maintain TE modes i.e. (TEx, TEy and TEz) which would radiate like short magnetic dipole. The resonant frequency of each mode is a function of DRA dimension. By properly choosing the DRA dimensions, the designer can avoid the unwanted modes to appear over the frequency band during operation. Resonant frequency of TE modes can be calculated by solving the transcendental equation [1].

$$k_x \tan(\mathrm{k}_x \mathrm{d}/2) = \sqrt{(\varepsilon_r - 1)\,\mathrm{k}_0^2 - k_x^2} \qquad \textbf{(2.7)}$$

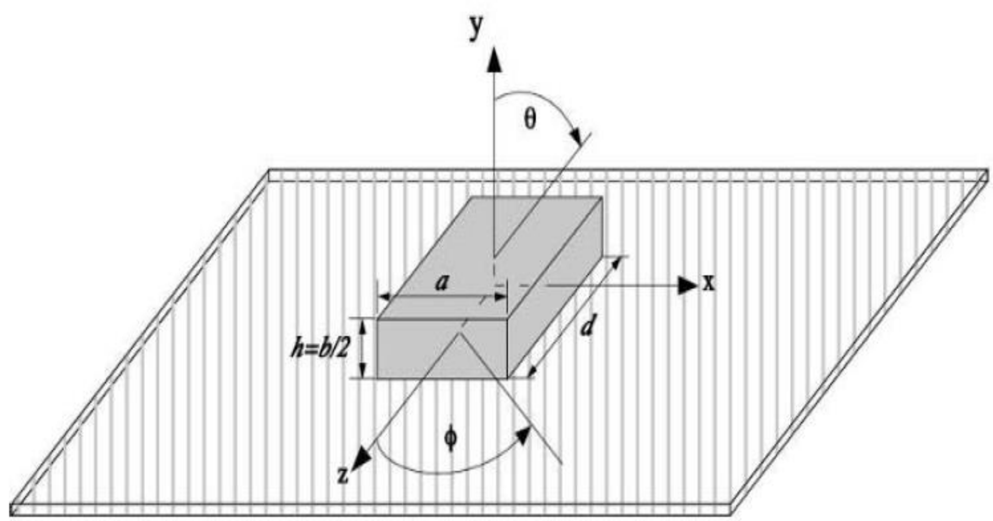
Here, free space wave number

$$(k_0) = \frac{2\Pi f_0}{c} \quad , k_x = \frac{m\Pi}{a} \quad k_y = \frac{n\Pi}{b} \quad , k_z = \frac{l\Pi}{d}$$

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \qquad \textbf{(2.8)}$$

2.5.3.1 Dielectric waveguide model:

Dielectric waveguide model may also be applied for an isolated DRA in free space. Here we have studied about field configuration, resonant frequency as well as the Q-factor.



DRA on ground plane

Figure 2.9 Geometry of the dielectric resonator model

2.5.3.2 Field configuration:

$TE^{z}_{10\delta}$ Mode is using for rectangular DRAs having dimensions a, b>d. With dielectric waveguide model, following fields can be calculated [2].

$$H_y = \frac{(k_y k_z)}{j\omega\mu_0} \sin(k_x x)\cos(k_y y)\sin(k_z z) \qquad \textbf{(2.9)}$$

$$H_z = \frac{(k_x^2 + k_y^2)}{j\omega\mu_0} \cos(k_x x)\cos(k_y y)\cos(k_z z) \qquad \textbf{(2.10)}$$

Electric field for x, y and z dimensions can be calculated by:

$$E_x = k_y \cos(k_x x)\sin(k_y y)\cos(k_z z) \qquad \textbf{(2.11)}$$

$$E_y = -k_x \sin(k_x x)\cos(k_y y)\cos(k_z z) \qquad \textbf{(2.12)}$$

$$E_z = 0 \qquad \textbf{(2.13)}$$

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \qquad \textbf{(2.14)}$$

2.5.3.3 Resonant frequency:

By using transcendental equation, the value of k_z is calculated. The normalized resonant frequency will be determined by solving k0 in equation (2.34). The normalized frequency is:

$$F = \frac{2\Pi a f_0 \sqrt{\varepsilon_r}}{c} \qquad \textbf{(2.15)}$$

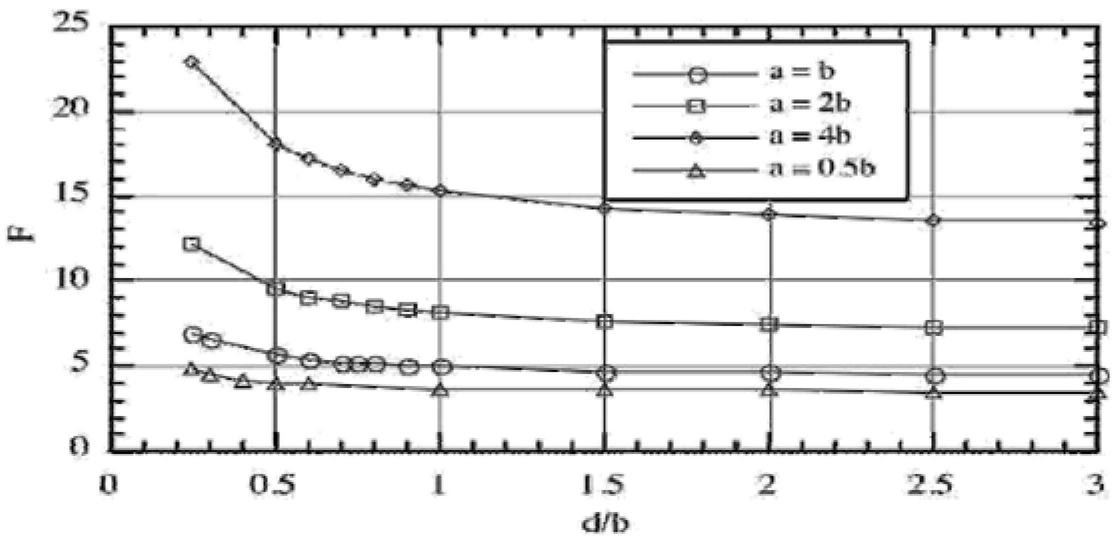


Figure 2.10 Normalized frequency of a rectangular DRA

In fig 2.10, the curves plot the normalized frequency (F) versus ratio of DRA dimensions d/b for various ratio of a/b. Here, these curves are used to calculate resonant frequency of DRA without using transcendental equation. In example, the different dimensions have taken for calculating resonant frequency are _r=10, a= b= d= 10 mm, at d/b=1, the value of F=5 and f0= 7.55 GHz [2].

$$W_e = \frac{\varepsilon_0 \varepsilon_r abd}{32}(1 + \frac{\sin(k_z d)}{k_z d})(k_x^2 + k_y^2) \qquad \textbf{(2.16)}$$

$$P_{rad} = 10 k_0^4 \left| P_m \right|^2 \qquad \textbf{(2.17)}$$

2.5.3.4 Q-factor:

Q-factor of the DRA will be obtained by using:

$$Q = \frac{2\omega W_e}{P_{rad}} \qquad \textbf{(2.18)}$$

Here, W_e = stored energy

P_{rad} = radiated power

We and P_{rad} can be calculated by,

Where Pm is the magnetic dipole moment of DRA:

$$P_m = \frac{-j\omega 8\varepsilon_0(\varepsilon_r - 1)}{k_x k_y k_z}\sin\left(\frac{k_z d}{2}\right)\hat{Z} \qquad \textbf{(2.19)}$$

By using Q-factor equation, we can calculate impedance bandwidth of the DRA:

$$BW = \frac{S-1}{Q\sqrt{S}} \qquad \textbf{(2.20)}$$

Where 'S' is the maximum acceptable voltage standing wave ratio. Figure 2.11 shows the graphs plots of normalized Q-factor as a function of DRA dimension d/b for different values of dielectric constant and a/b. Normalized Q-factor can be determined [2]

$$Q_e = \frac{Q}{\varepsilon_r^{3/2}} \qquad \textbf{(2.21)}$$

Chapter 3

Rectangular Dielectric Resonator Antenna Array for Wireless and Satellite Applications

3.1 Introduction:-

Generally radiation patterns of the single elements are wider enough; also every element provides lesser value for directivity (gain). This is the need of many applications to have highly directive antenna characteristics (higher gain) which will help to fulfill demands for long distance communication. It is achieved if we increase the electrical size of antenna. This is due to the fact that when the length of antenna increases, gain of antenna also increases but not beyond the length of 'λ' because linear antenna lose their characteristics. This is because as the length of the antenna increases their current travelling characteristics of the antenna changes. After certain length i.e. 'λ' antenna loses there characteristics, this led antenna to lose their performance. So, to supplement this we transfer our way of gain increment to antenna arrays. Generally in so many cases, elements of the antenna array remain identical. It is not mandatory, still more suitable, simple as well as more practical.

3.2 Antenna Array:-

Antenna array is used to direct the radiated power towards a desired angular sector. Antenna array is a process of placing many antennas' together in a proper spacing, proper phasing so that the individual radiations will meet the point of interest in a constructive way and in other directions cancel each other so as to get a very high directional pattern in the desired direction.

Several individual antenna's so spaced and phased that their individual contributions add in one preferred direction to give higher directivity gain and cancel in other direction. The new antenna built by multi-elements is called antenna array.

Once any array is constructed to direct power towards a desired direction, can be steering towards any other direction if we change relative phases of array elements. This method is called steering or scanning. A linear antenna element, along the z-direction, has an omnidirectional pattern with respect to azimuthal angle φ. By replication of the antenna element along x-ory-directions, azimuthal symmetry is broken. Some linear patterns of the array antennas are shown in the figure below. By properly choosing the array feed coefficients 'A_n', each required gain pattern g(φ)can be synthesized [14].

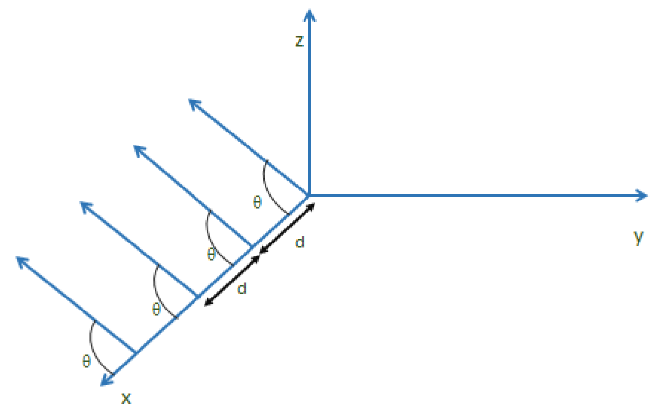


Fig.3.1 Antenna elements placed in x-axis

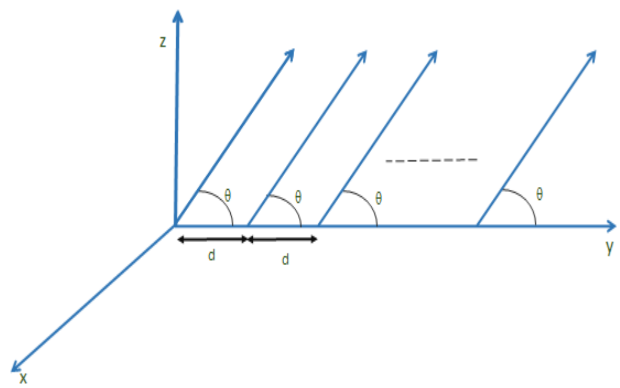


Fig.3.2 Antenna elements placed in y-axis

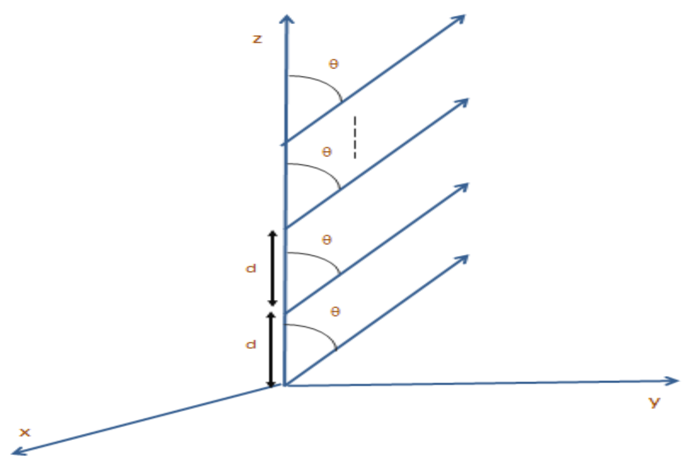


Fig.3.3 Antenna elements placed in z-direction

3.3 Principle of working:-

The principle of the antenna array is basically based on the constructive and destructive of the electric field in some particular directions. Total field of the array can be found out by adding the vectors of those fields radiated with the help of individual element. The field within the elements of array interfere constructively (add) in the required direction and interfere destructively (cancel) in the remaining space. But practically there is no fully cancellation, hence leads to some minor (side) lobes and back lobes. There are many optimization techniques used for the reduction of side lobes. Here in this paper we have used Genetic Algorithm to reduce the side lobe power.

There could be many parameters to reduce the side lobes i.e changes in the amplitude, phase change and distance between elements etc. The null steering in antenna radiation pattern of linear array to reject undesirable interference sources at the time of receiving the desired signal from a chosen direction receives significant attention during the past few years and still of great interest.

Here we have preferred amplitude optimization because of its simplicity and easy to work with fixed antenna array. The basic principle of amplitude modulation is that the power of the dominating elements is increased and the other element power is reduced, this leads to the increase in the directivity (gain) and hence reliable for long distance communication.

3.4 Controlling factors of array:-

3.4.1. Excitation amplitude of the individual elements

Side lobe reduction of pattern can be achieved if we control the amplitude of every single individual elements of the array. This technique is very useful in RADAR communication, satellite communication and other communication systems to improve the signal to noise ratio and hence improve the performance of the system by reducing the undesired signals.

Here the amplitude of the individual elements is given with different value of excitation. The dominating elements are given large excitation when compared to the other elements. This causes improvement in the signal to noise ratio in the desired direction.

3.4.2. Excitation phase of each individual elements:-

Side lobe reduction of pattern can be achieved if we control only the excitation phase of each individual elements of the array. The working of this method can be well understood by checking the phase of individual element i.e. giving phase to each individual element in such a manner that it gives constructive electric field in the desired direction and destructive electric field in the unwanted directions. This does not need extra power to have good performing antenna system for long distance communication. This technique is very useful in satellite communication and other microwave communication systems to improve the signal to noise ratio and hence improve the performance of the system by reducing the undesired signals.

3.4.3. Relative spacing or displacement of the individual elements:-

Side lobe reduction of the pattern can be achieved by controlling the relative spacing or displacement of individual element. Spacing between the elements varies to get highly directive antenna. This method is used only for the specific purpose as it is not practically possible every time to shift the antenna element from one place to the other [5].

3.5. Array Factor of Linear Antenna Array:-

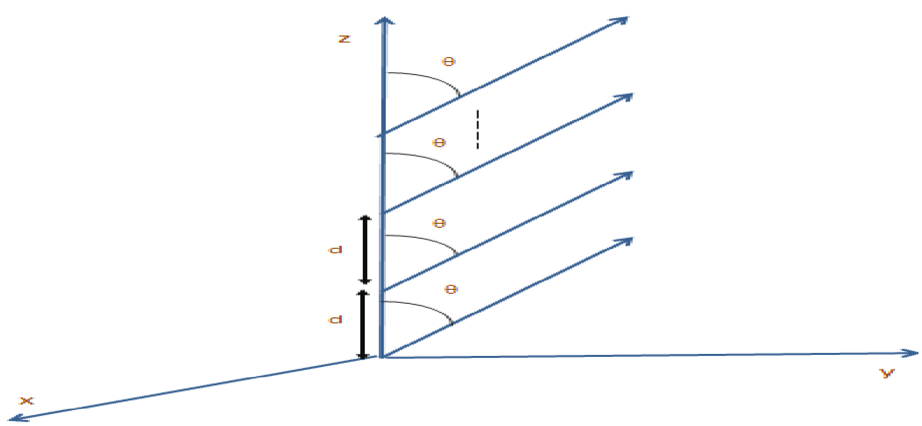


Fig.3.4 Far field geometry of N-element array of isotropic sources positioned along z-axis.

Let us take that each element has the same amplitude but every succeeding elements have β progressive phase shift in the current excitation relative to preceding element. Spacing between elements is constant, hence called uniform array [5]. The elements are considered to be point sources for finding the array factor.

The array factor is given as,

$$AF = 1 + e^{+j(kd\cos\Theta + \beta)} + e^{+j2(kd\cos\Theta + \beta)} + \ldots\ldots.. + e^{+j(N-1)(kd\cos\Theta + \beta)} \quad (3.1)$$

$$AF = \sum_{n=0}^{N-1} e^{jnkd\cos\theta + \beta} \quad (3.2)$$

This can also be written as,

$$AF = \sum_{n=0}^{N-1} |An| \, e^{jn\Psi} \quad (3.3)$$

$$\text{Where} \quad \Psi = kd\cos\Theta + \beta \quad (3.3.a)$$

It can be illustrated from the above that the total Array Factor is controlled in uniform array if we select properly relative phase Ψ between the elements. If we say the array antenna is non-uniform the total Array Factor formation and distribution can be controlled by properly selecting both the amplitude as well as phase.

3.6 Array Factor consideration for DRA arrays:-

3.6.1. Introduction:-

Dielectric Resonator antennas have some good performing properties which makes them better performing antenna than microstrip conducting patch antennas. These antennas are basically useful for millimeter wave and microwave applications. These peculiar properties are small size, high radiation efficiency, flexibility in the polarization of radiation pattern, low losses etc. The most important property of the DRA is immunity toward the surface wave power leakage as well as lower conducting loss [15], [16].

As we have seen that the dimension of the DRA element is not negligible with respect to inter – element distance, hence this is not well suited for compute array factor from conventional array theory. Here a corrective term is presented which includes coupling between array elements. This corrective term will only deal with the rectangular shape of DRA but the result is applicable to any shapes of the DRA because the process is based on numerical Finite Differences - Time Domain (FD-TD).

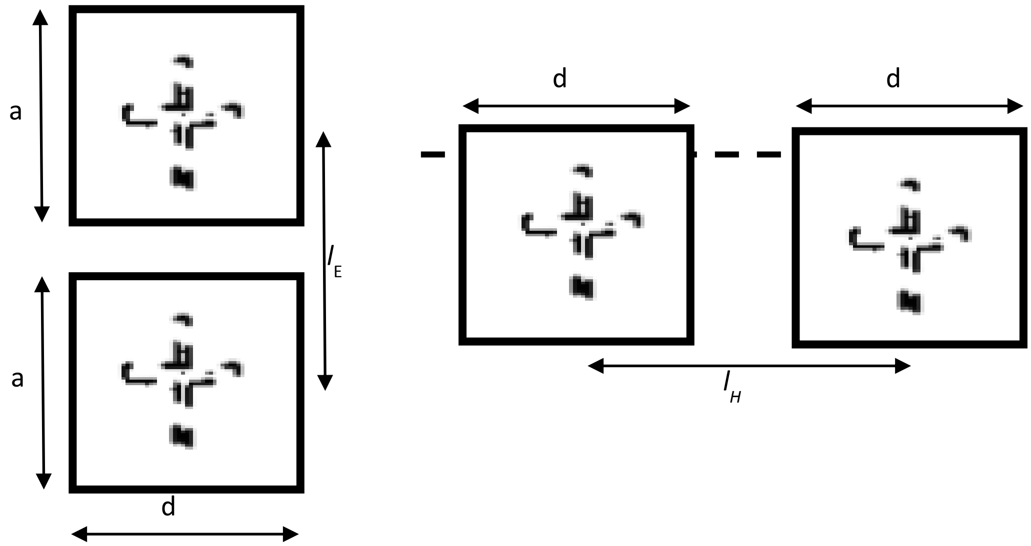
3.6.2. Formulation –

Take the slot-fed rectangular DRA as shown in the figure below. This shows the base element placed in the linear fashion aligned in the x-axis or can be placed in the z-axis. We will refer this alignment as E-set up as well as H-set up and the inter element distance measured between centers of DRA as l_E and l_H respectively [15].

Suitable methods to find the array factor state that radiation pattern of these array may be calculated by the superposition of an element factor. This is given by a single isolated DRA, and is given as

$$\text{AF}= \sum_{n=0}^{N-1} |A_n| e^{jnk_0 l_{[\text{E,H}]} \cos\theta + \beta} \tag{3.4}$$

Where $A_n = |A_n| e^{jn\phi}$, the feed amplitude for element n =0,…, N-1. θ is angle of observation direction from array axis. These array factors takes electrical distance between elements as $k_0 l_{[E,H]}$ as if it were completely in free space. Here the case is somewhat different than conventional case because of the dimensions of DRA i.e. '*a'* and '*d*' are not negligible with respect to inter-element distance $l_{[E]}$, as well as $l_{[H]}$ respectively. Hence a corrective term is introduced where it is suggested to consider phase centers between DRA's.



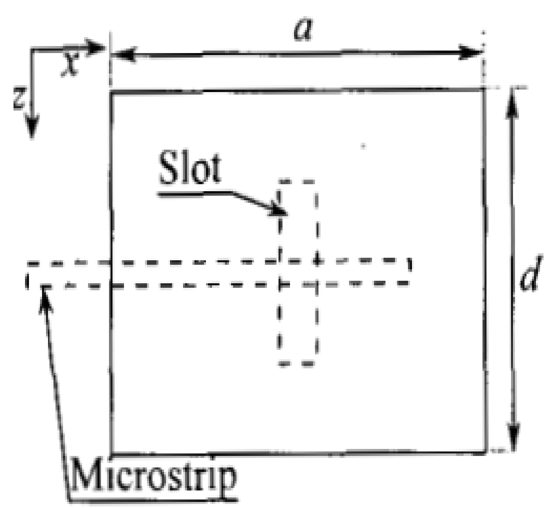


Fig.3.5 - DRA geometry

The corrected array factor for the DRA can be given as,

$$AF = \sum_{n=0}^{N-1} |In| \, e^{jn\{[k_o(l_{[E,H]} - [a,d]) + k_{[x,z]}[a,d]]\cos\theta + \beta\}} \tag{3.5}$$

Where,

$k_{[x,z]} \longrightarrow$ Relative resonant mode wave number for the portion of the distance which is within the DRA

$k_o \longrightarrow$ Free space wave number

$k_o l_{[E,H]} \longrightarrow$ Electrical distance between the elements, as if it is completely in free space

This above array factor allows greater accuracy since it takes into account the effective phases of the field at the faces of the DRA's, but it is not highly accurate since it does not take the coupling between the elements. This coupling is so far negligible for the set up used here and changes the field behavior in the resonator.

Here a more accurate method to find the $k_{[x,z]}$ is introduced. Using FD-TD analysis of two element array, it is defined that the structure can be seen as the two port network and can be used to find the S_{12}. Finding the phase of the S_{12} parameter and de-embedding the microstrip line length and the electrical length $l_{[E,H]}$ -[a,d] in free space it is possible to calculate the delay between the feeding point at the center of the DRA and the DRA faces, that is, the corrective term in the above equation (3.5).

$$k_{[x,z]}[a,d] = \angle S_{11} - k_0 (l_{[E,H]} - [a,d]) \qquad \textbf{(3.6)}$$

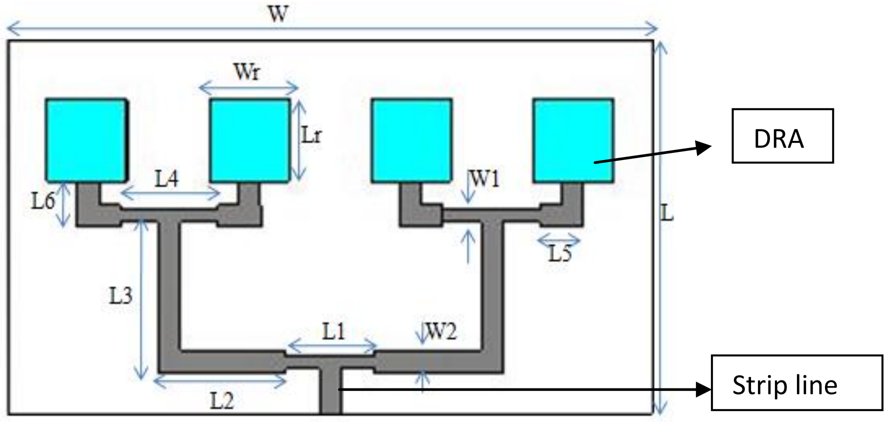
3.7 Design of Rectangular Dielectric Resonator Antenna (DRA) Array for Wireless and Satellite Applications:-

3.7.1 Introduction:-

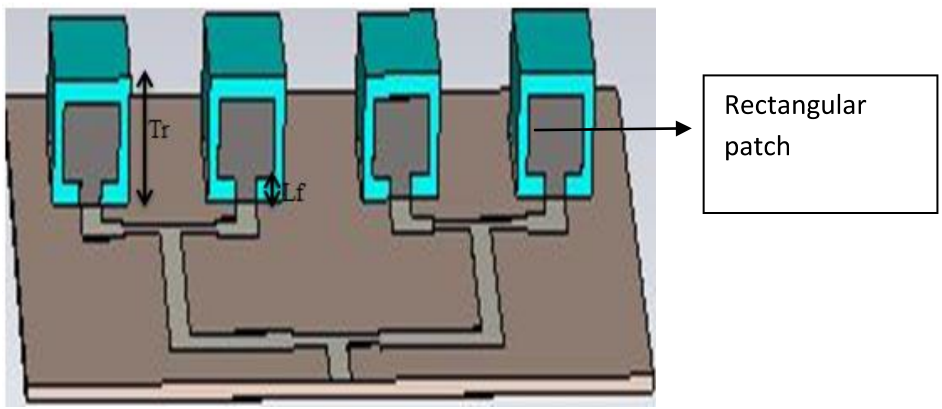
Bandwidth enhancement and low side lobe level is the main criteria for any wireless system to work very efficiently hence bandwidth enhancement is the main design concern of dielectric resonator antennas. The enhancement of the bandwidth can be theoretically seen by choosing the low value of dielectric constant with appropriate dimensions. This is because a low value of Q-factor is obtained which implies that it is theoretically possible to design cylindrical and rectangular DRA with very broad bandwidth. There are certain methods to improve the bandwidth of the DRA such as changing the shape of the DRA, modified feed geometry etc. Here we proposed a method to improve the impedance bandwidth of the DRA by making hybrid antennas, a simple method used that has a combination of a DRA with either microstrip patch or monopole antenna and by reducing the length of the ground plane. An introduction of air gap between dielectric resonator and the ground plane may also improve impedance bandwidth of DRA. Also there are some different methods to increase the impedance bandwidth for different shapes of DRA such as dual-mode rectangular DRAs, microstrip fed DRA, notched rectangular DRA, inverted stepped pyramidal DRAs.

3.7.2. Antenna Design:-

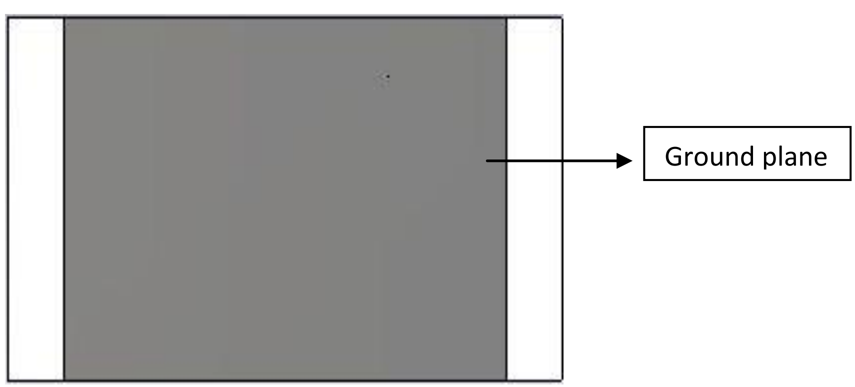
Here I proposed a 4-element Rectangular Dielectric Resonator Antenna (RDRA) array fed by microstrip line with rectangular patch (RP) for satellite application. Wilkinson power divider method is used to divide same power between the DRAs. The performance of the proposed antenna array such as S-parameter, radiation pattern, input impedance, gain and directivity has been analyzed and discussed. In this paper we design a 4-element rectangular DRA of permittivity ε_r 10.2 (Roger) is designed and simulated at 6 GHz. The DRA is fed directly with 50Ω stripline that has a dimension of 3x 0.05 mm^2.This microstrip line is photo-etched on substrate of permittivity ε_r= 4.4. The substrate dimension is 90×50 $mm^{2(}$W×L). The bottom side of the substrate makes the ground plane dimensioned as 90×50 mm^2 (Wg×Lg). The RDRA resonators are of square cross section of dimension 11×11 mm^2 (Wr×Lr) having thickness Tr= 12 mm. The excitation used is rectangular conformal patch of size 8×7.5 mm^2 (Wc×Lc) connected with the microstrip corporate feed arrangement. For impedance matching, 50Ω lines and 70.5Ω lines are used in the microstrip feed line. The dimensions for the feed line are W1= 3 mm, W2= 1.6 mm, L1= 14 mm, L2= 14.8 mm, L3= 17. 289 mm, L4= 14 mm, L5= 3.018, L6= 3 mm and Lf= 2.15 mm. There should be the proper spacing between the dielectric resonators to avoid mutual coupling.



(a) Front view



(b) 3-D view



(c) Bottom view

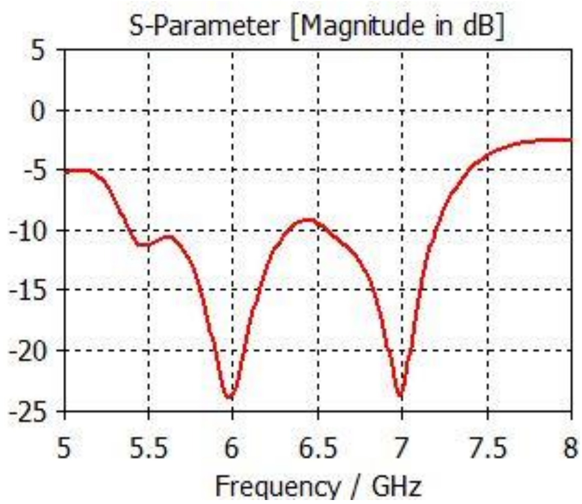
Fig. 3.6 Geometry of the proposed DRA array

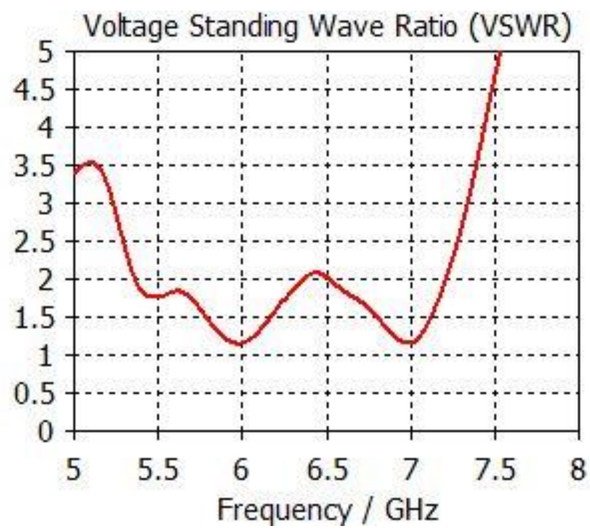
This structure can be well optimizing through any of the optimization technique, the optimization technique used here is the canonical genetic algorithm technique.

3.7.3 Result and Discussions:-

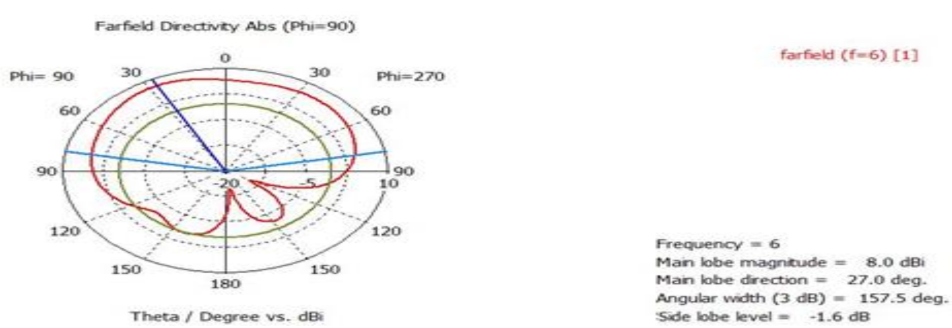
The results have been generated using the commercial 3D full wave electromagnetic (EM) simulation software CST Microwave studio.

<u>Unoptimized result</u>:-





(a) **(b)**



(c)

Fig.3.7 Unoptimized (a)Return loss (S_{11}), (b) Voltage Standing Wave Ratio (VSWR), (c) Farfield directivity plots

Here the fig.3.7 shows the unoptimized results,where the return loss plot have a notch at the 6.5 GHz frequency. Due to this the bandwidth covered is less and the VSWR is also large enough to degrade the performance of the antenna array. From fig.3.7 (c), shows that the sidelobe level is large enough to degrade the performance of the array antenna. Hence some technique is required to get rid from these problems. We do this provition through the Genetic Optimization technique using matlab.

Optimized results:-

Here we use genetic algorithm for distance optimization. The code has been written in matlab, which gives some specific distance values between the elements. The structure is then designed in the CST microwave studio 2011^{TM} and the results have been obtained and compared with the unoptimized results.

The optimized structure is shown below,

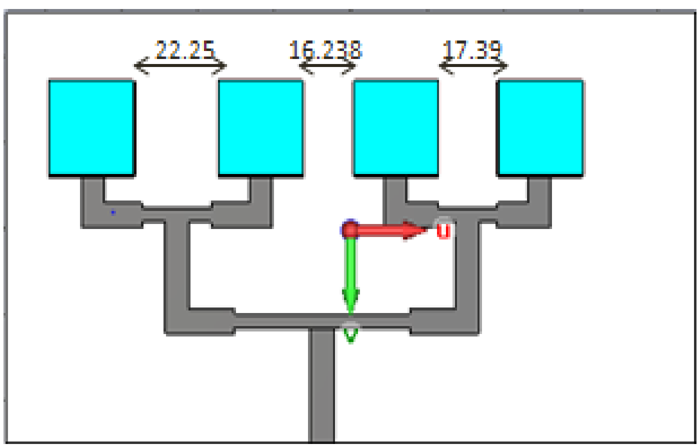
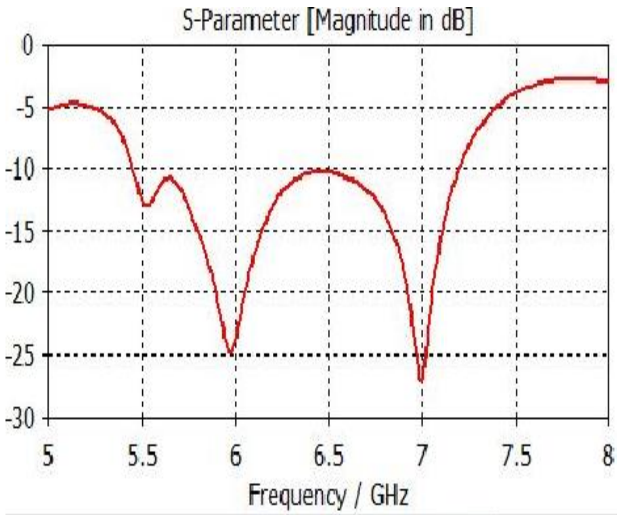
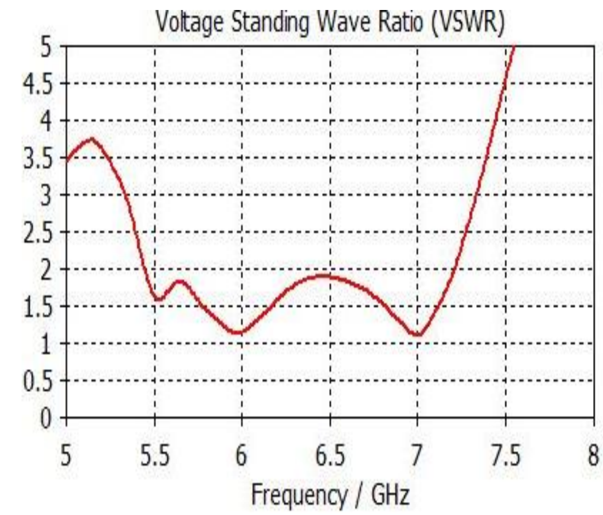


Fig.3.8 optimised structure of antenna array

The dimensions of DRAs and feeding patch is identical to the proposed antenna array, but the spacing between the DRA elements is changed and accordingly wilkinson power divider also get changed to get the optimum results.



(a)



(b)

(c)

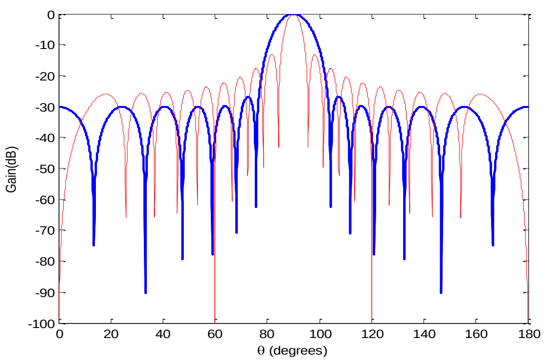
Fig.3.9 Optimized (a)Return loss (S_{11}), (b) Voltage Standing Wave Ratio (VSWR), (c) Farfield directivity plots

Simulated farfield result in fig.3.9 shows that the magnitude of the main lobe is about 10.6 dBi and the angular width (HPBW) which is better than the unoptimized results, also the sidelobe level is reduced to a certain amount. The VSWR is below 2 in between the band from 5.4 to 7.2 GHz. The return loss is also reduced significantly and hence the bandwidth is increased.

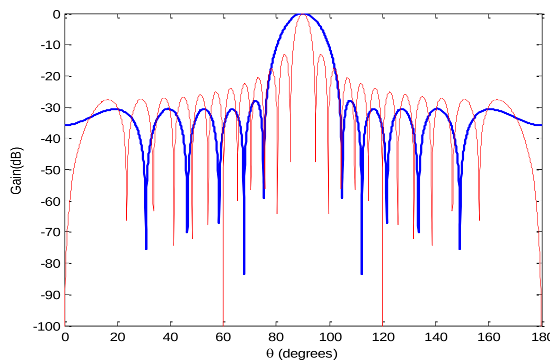
3.7.3.1 Genetic Optimization Results (using MATLAB 2012):-

The above structure is optimized through the canonical genetic algorithm. There are mainly three steps i.e. Selection, Crossover and Mutation. The plot obtained here is compared with the uniform amplitude and uniform spacing plot. The plots obtained here is from MATLAB 2012. Here the radiating source is considered as the point source or isotropic antenna source.

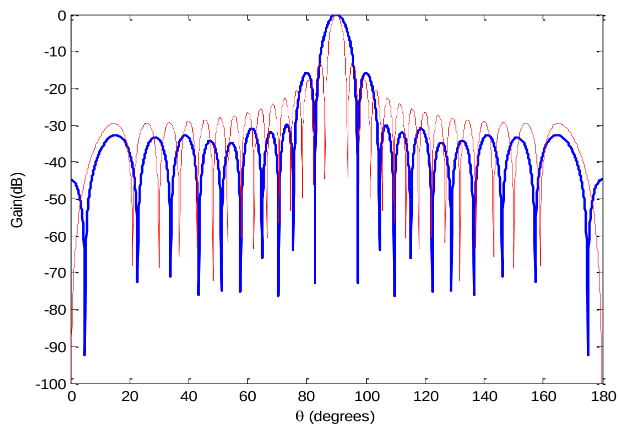
(i)<u>Amplitude Optimization</u>:-



(a)



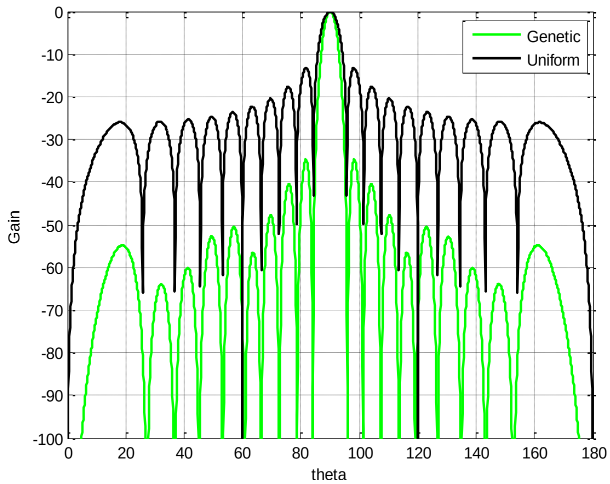
(b)



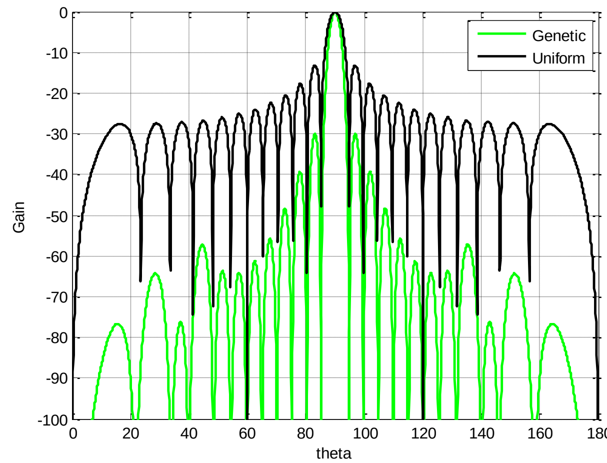
(c)

Fig. 3.10 Amplitude Optimization for (a) N=20 elements, (b) N=24 elements and (c) N=30 elements

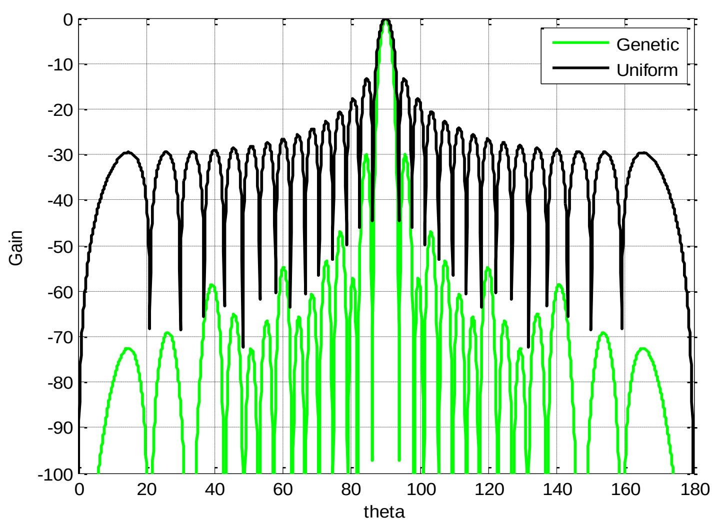
(ii) <u>Distance Optimization</u>:



(a)



(b)



(c)

Fig. 3.11 Distance Optimization for (a) N=20 elements, (b) N=24 elements and (c) N=30 elements.

Here the result obtained from MATLAB 2012 is not very much close to the result generated by CST microwave studio 2011^{TM} because the source antenna in MATLAB is by default isotropic point source and also the environmental losses are not taken into account in MATLAB.

<u>Result for distance optimization(using MATLAB):-</u>

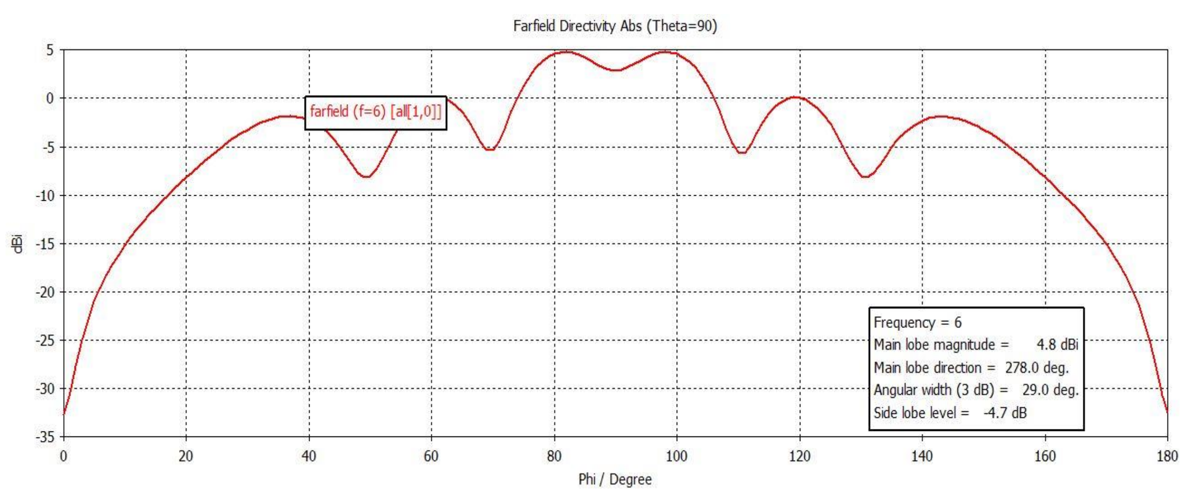
Table: 3.1

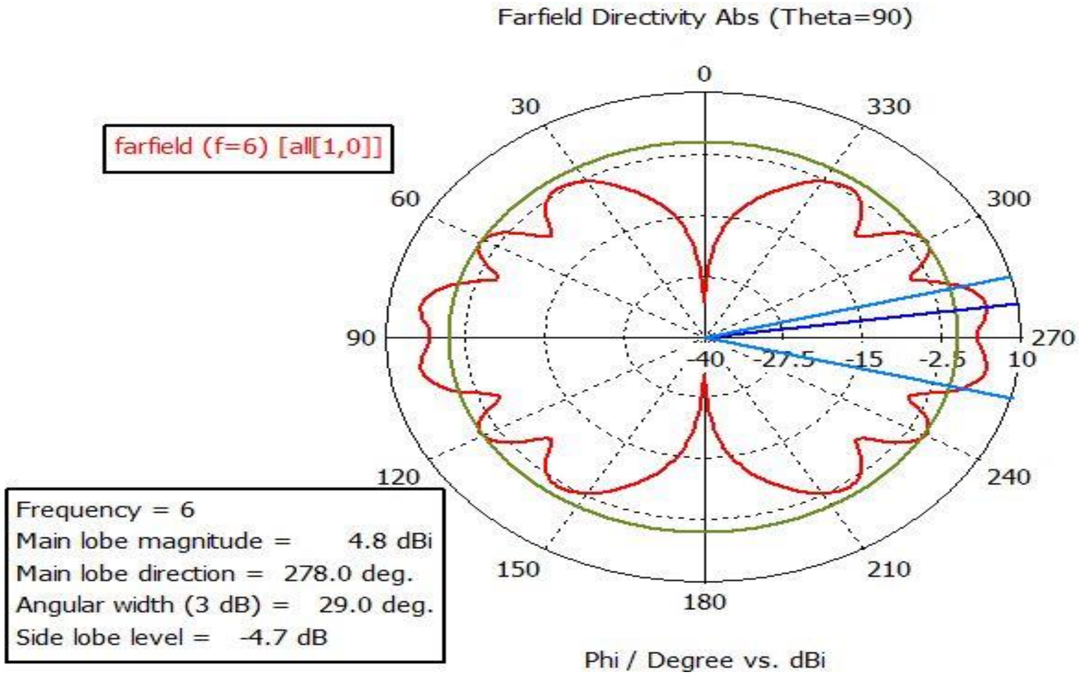
No. of elements	Unoptimized directivity (dBi)	Optimized directivity (dBi)	Unoptimized HPBW (degree)	Optimized HPBW (degree)
10	10.5	11.7	18	16.5
20	12.4	14.2	11	9
24	13.2	15.9	8.5	7.5
30	15.1	17.2	6	5

3.8 Validation of the algorithm:-

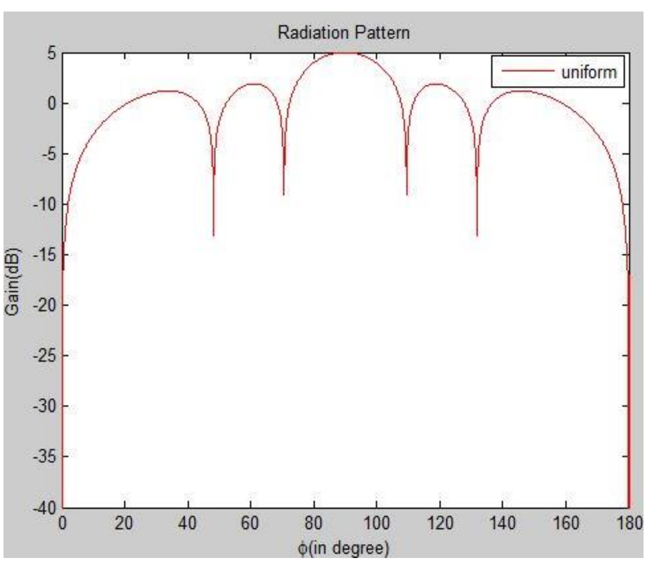
We take the results developed by CST and match it with the MATLAB oriented result for uniform spacing and excitation. If it is going to be similar with sufficient accuracy that means the algorithm we are working with is correct.

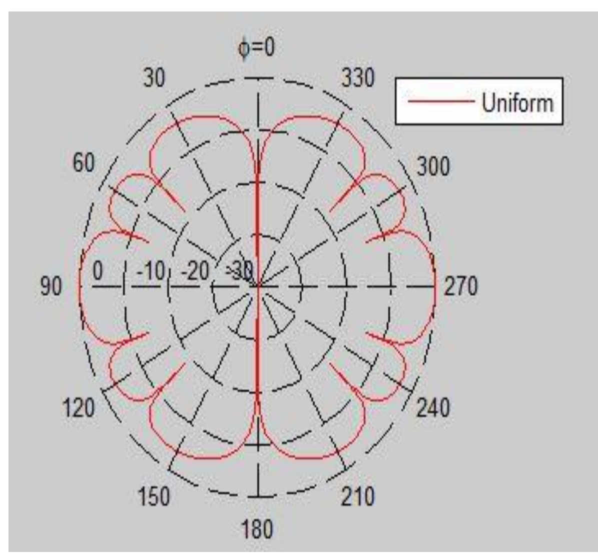
<u>CST RESULTS</u>:-





<u>MATLAB RESULTS</u>:-





Here the Results of CST and MATLAB matches to some extent hence we have validate the algorithm.

Chapter 4

CONCLUSION AND FUTURE WORK

4.1 Conclusion:-

This paper presents the 4-element Rectangular Dielectric Resonator Antenna array for wireless applications mainly for satellite application. The simulated results shows the unoptimized results have large VSWR, high side lobe level and high return loss. The optimized results show that the designed antenna covers the frequency range from 5.4 to 7.2 GHz (partial C-band) which covers several important applications in satellite communication. This can be used for uplink carriers in the range (5.925 GHz to 6.425 GHz). For satellite communications, the microwave frequencies of the C-band perform better under adverse weather conditions in comparison to other bands. VSWR is below 2 in the band between 5.4 to 7.2 GHz hence proposed antenna can be used very efficiently. Return loss (S_{11}) is below -10 dB in the proposed band.

Now the optimization results generated from the MATLAB shows that the distance optimization gives better performing results when compared to amplitude optimization. This is because in amplitude optimization there is large increment in the half power beam width (HPBW) and hence decrease in the directivity when the side lobe level reduces significantly and this is unlikely in distance optimization i.e. there is no such decrement of directivity observed. In distance optimization small increase in the directivity is observed for large number of elements with the side lobe reduces below -30 dB.

4.2 Suggestions for Future Work:-

Based on observations while completing this thesis, the following topics were identified which would helpful for further investigation:

- Fabrication and measurements of Rectangular Dielectric Resonator Antenna array with Roger material will be carried out in future.
- Besides, the experience of designing DRAs with microstrip line feeding, Dielectric resonator array with dielectric image guide feeding can further be designed to minimize the metallic losses.

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