# DESIGN AND ANALYSIS OF DIELECTRIC RESONATOR ANTENNA


VIRENDRA KUMAR PATEL
Roll No. – 13-1-4-111

DEBAJIT BORAH
Roll No. – 13-1-4-018

ADITYA KUMAR CHAUDHARY
Roll No. – 13-1-4-115

**Electronics and Communication Engineering**
**National Institute of Technology**
**SILCHAR-788010**

# ABSTRACT

***Present scenario of communication, all wired ones becoming as wireless. So, to achieve efficient and affordable communication in wireless technology, compact and efficient radiators required. One of the efficient radiators is dielectric resonator antenna (DRA). Almost all the applied power will be lost in the radiated fields only, with this attractive feature DRAs become much popular in wireless communication field at microwave frequencies. In this project, new type of DRAs designed for popular wireless applications like Wireless Interoperability Microwave Access (WIMAX), Wireless Local Area Network (WLAN) and Wireless Fidelity (Wi-Fi). This project is used to get the multiple resonant frequencies and wide bandwidths. The first stacked DRA is covering the resonant frequencies at 5.20GHz, 5.84GHz which covers WLAN bands and second stacked DRA resonating at 3.5GHz and 5.5GHz, which covers Wi-MAX and WLAN bands respectively. This project work concludes that, the designed DRAs efficiently radiates at IEEE - 802.11a/b/g and IEEE-802.16 bands.***

## Table of Contents

## 1.1 Introduction

***Wireless Communications are becoming as a part of day-to-day life of human beings. So, to achieve efficient and affordable wireless communications, compact and efficient radiators required. Indeed,one of the efficient radiators is dielectric resonator antenna (DRA).The dielectric resonator***

*antenna efficiently radiates at microwave frequencies. DRA is economically affordable and it is having desirable features like - easy design, simple fabrication methods and gives flexibility in design and to analyse the results in order to achieve required resonant frequencies depending upon our coverage requirements. In general DRA having high-radiation efficiency, bandwidth and polarization flexibility make them by far superior and better replacement to conventional microstrip patch antennas (MPA). DRAs are intrinsically immune to those surface wave power leakage and conductor loss problems, which plagues the MPA and reduces their efficiency. DRA consists of high dielectric constant materials, high quality factors and mounted on a grounded dielectric substrate of lower permittivity [1]. DRA is fabricated from low-loss and high relative dielectric constant material of various shapes whose resonant frequencies are functions of the shape, dimensions of the shape and permittivity of the material. DRA can be in a few geometries including cylindrical, rectangular, spherical, half-split cylindrical, disk, and hemispherical shaped [1]. The DRAs have properties such as very less phase noise, small size, stability in frequency and temperature, ease of integration with existing technologies and other hybrid MIC circuitries, flexible construction and the ability to withstand harsh environments. The DRA has some interesting characteristics, like small size, ease of fabrication, high radiation efficiency, increased bandwidth and low production cost. DRAs are very promising for applications in wireless communications like Wireless Local Area Networks.*

## 1.2 Literature Review

*Wireless communications have grown at a very rapid pace across the world over the last few years, which provide a great flexibility in the communication infrastructure of environments such as hospitals, factories, and large office buildings [2]. Dielectric Resonator Antennas (DRA)'s became very popular in the core sectors of a country like defence, military, radar and especially for satellite and millimetre wave applications. The resonating frequencies of a DRA are nothing but the function of size, shape and dielectric constants only. Due to this flexibility in DRAs, they can be designed with different shapes as per coverage requirements depending upon the applications in the wireless communication industries. For many years, the dielectric resonator (DR) has primarily been used in microwave circuits, such as oscillators and filters, where the DR is normally made of highpermittivity material, with dielectric constant $\varepsilon r > 20$. The unloaded Q-factor is usually between 50 and 500, but can be as high as 10,000. Because of these traditional applications, the DR was usually treated as an energy storage device rather than as a radiator [2]. DRAs can also be excited with different feeding methods, such as microstrip lines, dielectric image waveguide feeding, aperture coupling, probes, slots, and co-planar lines. The DRAs are good replacement for the Microstrip antenna, because the DRA has a much wider impedance bandwidth and higher power handling capability due to their many advantageous and attractive features. As such, these include their flexibility in design, light weight, compact size, the versatility in their shape and feeding mechanism, simple structures, easy fabrication and wide impedance bandwidth.*
*Wireless communications is, by any measure, the promptest growing segment of the*

*communications industry in wireless field. As such, it has captured the attention of the media and the imagination of the public, end users and consumers. Cellular systems have experienced exponential growth over the last decade and there are currently around two billion users worldwide. Indeed, the cellular phones have become a critical business tool and part of everyday life in most developed countries, and are rapidly supplanting antiquated wire line systems in many developing countries. In addition, wireless local area networks (WLAN) currently supplement or replace wired networks in many homes, businesses, and campuses. Many new applications, including wireless sensor networks, automated highways and factories, smart homes and appliances, and remote telemedicine, are emerging from research ideas to concrete systems. The explosive growth of wireless systems coupled with the proliferation of laptop and palmtop computers indicate a bright future for wireless networks, both as stand-alone systems and as part of the larger networking infrastructure. However, many technical challenges remain in designing robust wireless networks that deliver the performance necessary to support emerging applications* .

## 1.3 Thesis Motivation

*Dielectric resonator antennas (DRA) possess some attractive characteristics which are making them as very promising and affordable at microwave frequencies for wireless applications especially for WLAN applications. Wireless Communications are becoming part in day-to-day life of public. So, to achieve efficient wireless communications, efficient radiators required. Definitely, one of the promising radiators is nothing but dielectric resonator antenna (DRA). The dielectric resonator antenna efficiently radiates at millimetre-wave frequencies. DRA is economically affordable. DRA has desirable features like - easy design, simple fabrication methods and gives flexibility in design and to analyse the results in order to achieve required resonant frequencies depending upon our coverage requirements. In this thesis we will find the design of dielectric resonator antenna and analysing for optimizing the antenna parameters through parametrical studies.*

## 1.4 Scope of this Project

*The scope of this project work is to design and fabrication of a Dielectric Resonator Antenna which can be used for narrow band specific wireless applications according to the Federal communication commission specifications. That is used the operating frequencies like WiMAX, WLAN, Wi-Fi etc. and the antenna should be small in size and easy-to-manufacture with available laboratory equipment. The return loss must be less than -10 dBi at wireless frequencies, which means only 10% of power will be reflected back while 90% of power is transmitted. Other aspects, such as beam width, side lobes, VSWR, Polarization, Impedance measurements were not considered during the design stage.*

*Special attention had paid in design stage to get the double bands at a time by optimizing the feeding techniques and structures of the dielectric resonators.*

# Antenna Parameters

## 2.1 Radiation pattern

*The basic term "radiation" means that, the distribution of power through respective fields of antenna. An antenna radiation pattern or antenna pattern is defined as "A mathematical function or a graphical representation of radiation properties of the antenna as a function of space coordinates". However, in most cases the radiation pattern is determined in the far field region and is represented as function of directional coordinates. The properties of Radiation are power flux density, radiation intensity, field strength, directivity phase or polarization. The radiation properties of most concern are the two or three dimensional spatial distribution of radiated energy as function of the observer's position along a path or surface of constant radius. A trace of received power at constant radius is called power pattern. On the other hand, a graph of spatial variation of the electric (or magnetic) field along constant radius is called amplitude field pattern. In practice the dimensional pattern is measured and recorded in series of two dimensional patterns .*

## 2.2 Radiation Intensity

*Radiation intensity in given direction is defined as "the power radiated from an antenna per unit solid angle". The radiation intensity is far field parameter and it can be obtained by simply multiplying the radiation density by the square of the distance [4]. In the mathematical from it can be expressed as*

| | | | |
|---|---|---|---|
| *U=r2Wrad* | *(2.1)* | | |
| *U = Radiation intensity (W/Unit solid angle)*<br>*Wrad = Radiation intensity (W/m2)*<br>*The radiation intensity is also related to far-zone electric field of an antenna by* | | | |
| *=* | *[* | *+* | *(2.2)* |

*E = Far zone electric field intensity of the antenna*
*, =Far zone electric field component of antenna*
*= Intrinsic impedance of the medium.*

## 2.3 Directivity

*In the 1983, version of the IEEE standard Definition of terms for antennas, there has been a substantive change in definition of directivity, compared to definition of 1973 version. Basically the term directivity in the new 1983 version has been used to replace the term directive gain of the old 1973 version. In the 1983 version the term directive gain has been deprecated. According to authors of the new standard this change brings this standard in line with common usage among antenna engineers and with other international standard notably those of the international electrochemical commission (IEC) therefore directivity of an antenna defined as the ratio of radiation intensity in given direction from the antenna to the radiation intensity averaged over all directions. The average radiation intensity is equal to the total power radiated by the antenna divided by 4 . if direction is not specified the direction of maximum radiation intensity is implied. Stated more simply the directivity of non-isotropic source is equal to the ratio of it radiation intensity in given direction over that of isotropic source [3]. In mathematical form it can be written as*
*(2.3)*
*(2.4)*
*D = Directivity*
*= Maximum directivity*
*Radiation intensity (W/unit solid angle)*
*= Maximum radiation intensity (W/unit solid angle)*
*= Radiation intensity of isotropic (W/ unit solid angle)*
*Total radiated power (W)*
*(2.5)*
*(2.6)*
*(2.7)*
*= Radiation intensity in given direction contained in field component*
*= Radiation intensity in given direction contained in field component*
*= Radiation power in all direction contained in field component*
*= Radiation power in all direction contained in field component*

## 2.4 Gain

*Another useful measure describing the performance of antenna is the gain. Although the gain of antenna is closely related to the directivity, remember that directivity is measure that describes only the directional properties of the antenna, and it is therefore controlled only by pattern. Absolute gain of an antenna is defined as the ratio of intensity, in a given direction to the radiation intensity that would be obtained if power accepted by antenna were radiated isotropically. The radiation intensity corresponding to isotropically radiated power is equal to the power accepted by the antenna divided by 4 .In equation form this can be expressed as*

*Gain = (2.8)*
*In most cases we deal with relative gain, which defined as the ratio of power gain in a given direction to the power gain of reference antenna in its reference direction. The power input must be same for both antennas the reference antenna usually a dipole horn or any other antenna whose gain can be calculated or it is known. In most cases however the reference antenna is lossless isotropic source. Thus (2.9) When the direction is not stated the power gain is usually taken in direction of maximum radiation.*

.

## 2.5 Antenna efficiency

*The total antenna efficiency eo is used to take into account losses at the input terminals and within the structure of the antenna [3]. Such losses may be due, to two factors given below*
1. *Reflection because of the mismatch between the transmission line and the antenna*
2. *I2R losses (conduction and dielectric)*

*In general the overall efficiency can be written as*
*e*
*o = ereced*
*Where, eo = total efficiency*
*er = reflection efficiency*
*ec= conduction efficiency*
*ed= dielectric efficiency*

## 2.6 Half power beam width

*The half power beam width is defined as in a plane containing the direction of maximum of a beam the angle between two direction in which the radiation intensity is one half the maximum value of the beam often the term beam width is used to describe the angle between any two point on the pattern such as the angle between 10-dB points. In this case the specific point on the pattern must be described the 3- dB beam width.*

*The beam width of the antenna is very important figure of merit and is often used to as trade-off between it and side lobe level; that is as the beam width decreases the side lobe increases and vice versa. In addition the beam width of antenna is also used to describe the resolution capabilities of the antenna to distinguish between two adjacent radiating sources or radar targets. The most common resolution criterion states that the resolution capabilities of antenna to distinguish between two sources is equal to half the first null beam width (FNBW/2) which is usually used to approximate the half power beam width (HPBW). That is two sources separated by angular distance equal or greater than FNBW/2 = HPBW of an antenna with uniform distribution can be resolved. If the separation is smaller ten antennas will be tend to smooth the angular separation distance .*

## 2.7 Bandwidth

*The bandwidth of an antenna is defined as the range of frequency with in which the performance of antenna with respect to some charters tics conform to specified standard. The bandwidth can be considered to be a range of frequency on either side of centre frequency where the antenna characteristics are within acceptable value of those at centre frequency. For broad band antenna the bandwidth is usually expressed as the ratio of upper to lower frequency of acceptable operation. Because the characteristics of an antenna do not necessarily vary in the same manner or are even critically affected by the frequency there is no unique characterization of the bandwidth.*

### 2.7.1 Frequency Bandwidth

➢ **Narrowband** - *These antennas cover a small range of the order of few percent around the designed operating frequency.*

| | |
|---|---|
| *FBW =* | *(2.11)* |
| *Wher e,* | *Fh= higher frequency*<br>*Fl =lower frequency*<br>*Fc = central frequency* |

➢ **Wide band or broad band**- *these antennas cover an octave or two range of frequencies.*
*FBW = (2.12)*

➢ **Impedance Bandwidth**- *The impedance variation with frequency of the antenna element results in a limitation of the frequency range over which the element can be matched to its feed line.*

*✔Impedance Bandwidth is usually specified in terms of a return loss or maximum SWR (typically less than 2.0 or 1.5) over a frequency range conversion of bandwidth from one SWR level to another can be accomplished by using the relation between Bandwidth B and Q*

*✔(2.13)*

*✔% Impedance Bandwidth = (2.14)*

## 2.8 Voltage Standing Wave Ratio (VSWR)

*The standing wave ratio (SWR), also known as the voltage standing wave ratio (VSWR), is not strictly an antenna characteristic, but is used to describe the performance of an antenna when attached to a transmission line. It is a measure of how well the antenna terminal impedance is matched to the characteristic impedance of the transmission line. Specifically, the VSWR is the ratio of the maximum to the minimum RF voltage along the transmission line. The maxima and minima along the lines are caused by partial reinforcement and cancellation of a forward moving*

*RF signal on the transmission line and its reflection from the antenna terminals. If the antenna terminal impedance exhibits no reactive (imaginary) part and the resistive (real) part is equal to the characteristic impedance of the transmission line, then the antenna and transmission line perfectly obeys impedance matching condition [4]. In general, (2.15)*
*Where,*
*= maximum amplitude of RF voltage*
*= minimum amplitude of RF voltage*

## 2.9 Polarization

*In general polarization of an antenna is referred as, the orientation of radiation of that antenna. Polarization of an antenna in given direction is defined as the polarization of the wave transmitted by the antenna. When the direction is not stated the polarization is taken to be polarization in direction of maximum gain. In practice polarization of the radiated energy varies with direction from the centre of the antenna so that different part of the pattern may have different polarization. Polarization of radiated wave is defined as that properties of electromagnetic wave describing the time varying direction and relative magnitude of electric field vector specifically the figure traced as a function of time by the extremity of vector at fixed location at in space and sense in which it is traced as observed along the direction of propagation [4].*

- *Linear*
- *Circular*
- *Elliptical*

## 2.10 Input impedance

*Input impedance is defined as “the impedance presented by an antenna at it terminals or the ratio of voltage to current at pair of terminals or the ratio of the appropriate component of the electric to magnetic fields at a point”. In this section we are primarily interested in the input impedance at pair of terminals which are input terminals of the antenna [5].*
*(2.16)*
*= Antenna impedance at terminals*
*= Antenna resistance at terminals*
*= Antenna resistance at terminals*

# Dielectric Resonator Antenna

## 3.1 Introduction of Dielectric Resonator Antenna (DRA)

*The structure of DRA mainly consists of three basic components; they are first one Substrate, secondly ground (Perfect Electric Conductor) material etched on substrate and some dielectric resonating material placed above the ground, generally referred as "Dielectric Resonator (DR)". The designing of DRs and using them in structures of DRAs, discussed in chapters 5-8.*

- *Basically DR is an electronic component that exhibits 'resonance' for a wide range of frequencies, generally in the microwave band.*
- *If the DR placed in an open environment, Power will be lost in the radiated fields only. This fact makes dielectric resonators useful as antenna elements instead of elements in microwave circuits as energy storage devices .*

*Wi-MAX and WLAN are the standard-based technologies enabling the delivery of last mile wireless broadband access . WiMAX refers to interoperable implementations of the IEEE 802.16 wireless-networks standard which can operate at higher bit rates or over longer distances. It is capable of operating in 3.4-3.6 GHz frequency range as well as at 5.5 GHz band . While WLAN standards in the 2.4-GHz range have recently emerged in the market, the data rates supported by such systems are limited to a few megabits per second. By contrast, a number of standards have been defined in the 5-6 GHz range that allow data rates greater than 20 Mb/s, offering attractive solutions for real-time imaging, multimedia, and high-speed video applications. To achieve the necessary applications a high performance wide band antenna with high radiation efficiency are required . Over the past few years, the dielectric resonator antenna (DRA) has received extensive attention due to its several advantages such as low profile, light weight, low dissipation loss, high dielectric strength and higher power handling capacity . DRA can be in a few geometries including cylindrical, rectangular, spherical, half-split cylindrical, disk, hemispherical and triangular shaped.*

*The main purpose of design any antenna is to obtain a wide range of bandwidth. Several bandwidth enhancement techniques have been reported on modified feed geometries and changing the shape of the DRA. By using different bandwidth enhancement techniques in this thesis different shape of dielectric resonator antennas are designed and simulated. There is few soft wares available which allow the optimization of the antenna. Here, Simulation process was done by using Computer Simulation Technology (CST). In this thesis, have been design different shapes of single and multiple dielectric resonator antennas for wireless applications. Bandwidth enhanceme techniques are used to obtain a large bandwidth for particular resonant frequencies.*

## 3.2 Basic Characteristics of DRA

*DRA offers several attractive features including the fallowing characteristics:*

- *In DRAs, we can use a wide range of dielectric constants ( = 2.1 – 100), that allowing the designer to have control over the physical size of the DRA and its bandwidth.*
- *The Size of DRA is proportional to λ0/√ , where λ0 is the free space wavelength at the resonant frequency, and is the dielectric constant of the material.*
- *DRAs can be designed to operate over a wide range of frequencies from 1.3 GHz to 40 GHz .*
- *High radiation efficiency (95%) due to the absence of conductor or surface wave losses.*
- *Several feeding mechanisms can be used (including slots, probes, microstrip lines, dielectric image guide, and coplanar waveguide lines) to efficiently excite DRAs.*
- *DRA can be excited by several modes, many of which radiate pattern similar to short electric or magnetic dipoles, producing either broadside or Omni-directional radiation patterns for different coverage requirements [4].*
- *By choosing a dielectric material with low-loss characteristics, high-radiation efficiency can be maintained, even at millimetre-wave frequencies, due to an absence of surface waves and minimal conductor losses associated with the DRA*

- *A Wide control over size and bandwidth*
- *A tight tolerance: ± 1- 5%,*
- *A high quality factor Q: up to 10000 (f = 10GHz)*
- *A Wide range of temperature coefficient of resonance frequency: (-12…+30) ppm/oC*
- *A Tolerance ± 0.5; ±1.0; ±2.0 ppm/ oC.*

## 3.3 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 millimetre 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 considerably, 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 patch antennas, Dielectric resonator antennas 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, triangular, conical, hemispherical, etc. However, 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. Here, a*

variety of feed structures, which electromagnetic fields can be coupled to DRAs [6]. Usually common feed arrangements are coplanar waveguide feeding, 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, Figure 3.1 DRAs of various shapes (cylindrical, rectangular, hemispherical, low-profile circular-disk, low-profile triangular) 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 .
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. 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.

DRA 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:

❖ DRA has a much wide impendence bandwidth than microstrip antenna because it radiates through the whole antenna surface except ground port while microstrip antenna radiate only through two narrow radiation slots.
❖ Higher efficiency.
❖ Avoidance of surface waves is another attractive advantage of DRAs over microstrip antennas
❖ However, dielectric resonator antennas have some advantages:
❖ Light weight, low volume, and low profile configuration, which can be made conformal;
❖ DRA has high degree of flexibility and versatility, allowing for designs to suit a wide range of physical or electrical requirements of varied communication applications.
❖ Easy of fabrication
❖ High radiation efficiency
❖ High dielectric strength and higher power handling capacity
❖ In DRA, various shapes of resonators can be used (rectangular, cylindrical, hemispherical, etc.) that allow flexibility in design.
❖ Low production cost
❖ Several feeding mechanisms can be used (probes, slots, microstrip lines, dielectric image

guides, and coplanar waveguide lines) to efficiently excite DRAs, making them amenable to integration with various existing technologies .

## 3.4 Problems with Microstrip patch antenna

1) Narrow Bandwidth for Electrically thin substrates
2) High frequencies Results in,
a) More ohmic losses
b) Electrically thicker substrates which support surface waves and decrease radiation efficiency.
3) Low gain
4) Poor polarization purity
5) Spurious feed radiation
6) MPA having low dielectric strength, hence they cannot handle as much output power as other antennas

## 3.5 Advantages of DRA over Microstrip Antenna

In general Dielectric Resonator antennas having more attractive features compared to general microstrip patch antennas. The list of key advantages of DRAs over Microstrip patch antennas listed as fallows .

➢ Much wider Bandwidth
✔ More over operating Bandwidth of a DRA can be varied by the permittivity ( ) of the resonator material and its dimensions.
➢ Radiation efficiency is more
✔ Because DRA radiates through the whole antenna surface but in case of microstrip patch antenna radiates only through patch.
➢ Avoidance of surface wave and metal losses.
➢ DRA’s have high dielectric strength
✔ Hence DRA’s having higher power handling capacity.
✔ DRA’s can operate in a wide temperature range
More over the temperature stable ceramics enables the antenna to operate in a wide temperature range.

## 3.6 Bandwidth Enhancement by Using DRA's

*The key attractive feature in Dielectric Resonator antennas is Bandwidth Enhancement. By choosing proper structure for DRAs we can easily increase the bandwidth. The important techniques used in Bandwidth Enhancement by using DRA's as listed below [1].*

- *Optimizing the feeding mechanisms and the DRA parameters.*
- *Use of modified feed geometries (stub matching).*
- *Changing the shape of DRAs.*
- *Using Stacked Dielectric Resonators in DRA designs.*
- *Introduction of air gap between the ground and Dielectric Resonator.*
- *Changing the dielectric constant of Dielectric Resonator.*
- *Use of parasitic coupling with different resonators.*

*In present DRA structures the stacked method used to enhance the Bandwidth.*

## 3.7 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 various field mode configurations. These analyses can be used to predict the resonant frequency, radiation Q-factor, and radiation pattern of DRA .*

### 3.7.1 Cylindrical DRA

*Cylindrical DRA has advantages over hemispherical and rectangular shape DRA. It offers greater design flexibility, where the ration of radius/height controls the resonant frequency and the quality (Q) factor. By varying the DRA's dimensions different Q-factor can be obtained. In cylindrical DRA fabrication is much easier than hemispherical DRA and various modes can be easily excited which results in either broadside or Omni-directional radiation patters. It offers one degree of freedom more than the hemispherical shape; it has aspect ratio a/h which determines the Q factor for a given dielectric constant .*

*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 DRA which is a subclass of the cylindrical DRA that offers increased 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 the cylindrical DRA is shown in figure 3.2. It consists of a material with a height h, radius a, and dielectric constant ( ). This shape offers one degree of freedom more than hemispherical shape because it has aspect ratio a/h, which determines k0a and the Q-factor for a given dielectric constant .*

### 3.7.2 Hemispherical DRA

*Hemispherical shape DRA offers an advantage over the rectangular and cylindrical shapes as the interface between the dielectric and air is simpler. By that, a closed form expression cab obtained for the Green's function.*

*Figure 3.3 Configuration of a probe-fed hemispherical DRA*
*The hemispherical DRA is characterized by a radius a, a dielectric constant as shown in figure 3.3. Here, we assumed that the hemispherical DRA which is mounted on 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) and transverse magnetic (TM) are different modes in dielectric sphere. Transverse electric (TE) modes having a zero value for the radial component of the Electric field (Er=0), while transverse magnetic(TM) modes have a zero radial component of the magnetic field (Hr=0). The two fundamental modes for hemispherical DRA are TE111, whose radiation pattern is similar to a short horizontal magnetic dipole and TM101, whose radiation pattern is similar to a short electric monopole .*

### 3.7.3 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 can be divided into TE and TM, but with the DRA mounted on the ground plane only TE mode can typically excited. The rectangular DRA can maintenance TE modes (TEx, TEy and TEz) which would radiate like short magnetic dipole. The resonant frequency of each of these modes will be a function of the DRA dimensions. 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 .*

#### 3.7.3.1 Dielectric waveguide model

*Dielectric waveguide model can be used for an isolated DRA in free space. Here we studied about field configuration, resonant frequency and Q-factor .*

#### 3.7.3.2 Resonant frequency

*By using transcendental equation, the value of kHz is calculated. The normalised frequency is:*

*In figure 3.5, the curves plot the normalised frequency (F) versus the 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 [1].*

## 3.7.4. Stacked method

*A method for enhancing bandwidth in DRAs is stacking DRAs a top one another. In many cases with a single element DRA, desired specifications cannot be achieved. For example a high gain, directional pattern cannot be synthesized with a single DRA of any shape. In these applications, a DRA with appropriate element arrangement and feed configurations can be used to provide desired specifications. Dielectric Resonator Antennas (DRA's) have become popular in recent years because of many advantages they offer. The dominant mode radiation patterns in most of the probe-fed or slot fed structures are in the broadside direction of the elements. In DRAs stacked method is one of the highly efficient for bandwidth enhancement. Figure 3.6 shows a cylindrical stacked dielectric resonator antenna. The DRA stacked configuration contains two cylindrical discs of different materials vertically stacked, one atop the other, placed above a ground plane. Lower DRA is excited by a probe feed while the upper DRA is electromagnetically coupled, where the cylindrical DRA has radius (a), height (h) and relative dielectric permittivity ( r) .*

*Air gaps can also be introduced in between DRAs to enhance the impedance bandwidth. The parameters corresponding to the cylinders can take as per requirement. The main disadvantage of this method is that the DRA geometry is not very low profile [1].*

### 3.7.4.1. Co-planar parasitic method

*Regarding the mechanical structures and fabrications, Microstrip antennas have the advantage since etching can be used and the feeding mechanism and the antenna can be structured in one process with great accuracy in the alignment. The advantages become more appreciated in the structure of the arrays. DRA requires adhesive to mount the DR over the ground plane and more manual effort in the alignment of the DRA with the feeding structure.*
*Another method to enhance the impedance bandwidth of DRA is by using array technique.*
*In stack method, DRAs are stacking on top of each other that will add increment to the overall height of the antenna For certain applications, there is height restriction in DRA design. An alternative method is used to enhance bandwidth of DRA called a co- planar parasitic method where DRAs can also be placed on the same plane. Here, the centre element is excited by using any feeding method and adjacent elements are electromagnetically coupled. The main drawback is that here the problem becomes more pronounced in the structure of the array, where alignment of the individual elements and the array becomes more critical. The possible misalignment of the array elements could cause deterioration in the radiation characteristics of the antenna. To overcome this problem, it was suggested that the DRA array could be fabricated from a single sheet by perforating the area between the DRA elements with a lattice of holes .*

*Figure 3.7 shows the wideband configuration of three DRAs. Here, centre DR is connected* *with microstrip feed line. At the bottom there is ground and above it substrate placed. DRs placed above the substrate material .*

*Even though compared to stacked method, the Co-planar parasitic method facing few disadvantages like,*

- *Feeding process becomes complex compared to single feed stacked DR method.*
- *DRA requires more manual effort in the alignment of the DRA with the feeding structure*
- *Size requirements also very high, compared to single substrate stacked DR method.*

*Based on above factors generally we will prefer Stacked Dielectric Resonators for Bandwidth Enhancement.*

### 3.7.4.2. Embedded method

*The bandwidth of DRA can be enhancing by using embedded technique where DRAs can also embedded within one another .*

*Even though compared to stacked method, the Co-planar parasitic method facing few disadvantages like,*

- *Using multiple dielectric constant Dielectric Resonators making this method as complex, when compared to single dielectric constant stacked method.*
- *Dielectric Resonator positioning is less flexible compared to stacked method.*

*Based on above disadvantages generally we will prefer Stacked Dielectric Resonators for Bandwidth Enhancement at millimetre wave frequencies.*

# Feeding Methods

*There are several techniques available to feed or transmit electromagnetic energy to a dielectric resonator antenna. The five most popular feeding methods are the coaxial probe, slot aperture, microstrip line, co-planar coupling and dielectric image guide* .

## 4.1. Coaxial Feed

*The Coaxial feed or probe feed is a very common technique used for feeding dielectric resonator antennas as shown in figure 4.1. In this method, the probe can either be placed adjacent to the DRA or can be embedded within it. The amount of coupling can be enhanced by adjusting the probe height and the DRA location. In DRA, various modes can be excited depending on the location of the probe,. For the probe located adjacent to the DRA, the magnetic fields of the TE11δ mode of the rectangular DRA are excited and radiate like a horizontal magnetic dipole. For a probe located in the centre of a cylindrical DRA, the TE011 mode is excited and radiating like a vertical dipole. Another benefit of using probe coupling is that one can couple directly into a 50Ω system, without the requirement for a matching network. Probes are suitable at lower frequencies where aperture coupling may not be applied due to the large size of the slot required .*

## 4.2. Slot Aperture

*In slot aperture method, a DRA is exciting through an aperture in the ground plane upon which it is placed. Aperture coupling is applicable to DRAs of any shapes such as rectangular, cylindrical or hemispherical. The aperture works like a magnetic current running parallel to the size of the slot, which excites the magnetic fields inside the DRA. The aperture type of feeding consists of a slot cut in a ground plane and fed by a microstrip line below the ground plane. For avoiding spurious radiation, feed network is located below the ground plane. Moreover, slot coupling is an attractive technique for integrating DRAs with printed feed structures. The coupling level can be changed by moving the DRA with respect to the slot. Generally, a high dielectric material is used for the substrate and a thick, low dielectric constant material is used for the top dielectric resonator patch to optimize radiation from the antenna. The main drawback of this feed technique is that it is problematic to fabricate due to multiple layers, which also increases the antenna thickness. This feeding method also provides narrow bandwidth (up to 21%) .*

## 4.3.Microstrip Line Feed

*In this type of feed technique, a conducting strip is connected directly to the edge of the patch as shown in figure 4.3. A common method for coupling to dielectric resonators in microwave circuits is by proximity coupling to microstrip lines. Microstrip coupling will excite the magnetic fields in the DRA to create the short horizontal magnetic dipole mode. The level of coupling can be changed by the lateral location of the DRA with respect to the microstrip line and on the relative permittivity of the DRA .*

*In DRAs, the amount of coupling is generally quite small for requiring wide bandwidth. Microstrip lines can be used as a series feed for a linear array of DRAs. This is an easy feeding technique, since it offers ease of fabrication and simplicity in modelling along with impedance matching. However as the thickness of the dielectric substrate being used, rises, surface waves and spurious feed radiation also rises, which hampers the bandwidth of the antenna . One drawback of this method is that the polarization of the array is analysed by the orientation of the microstrip line such as the direction of the magnetic fields in the DRA will be parallel to the microstrip line*

*.*

## 4.4.Dielectric Image Guide

*Dielectric image guide is another attractive coupling technique in DRAs, as shown in figure 4.4. Dielectric image guides offer advantages over microstrip at millimetre –wave frequencies since they do not suffer as severely from conductor losses. As with microstriplines, the amount of coupling to the DRA is generally quite small, especially for DRAs with Slower permittivity values, although it may be possible to increase the coupling by operating the guide closer to the cut-off frequency. The dielectric image guide is thus best utilised as a series feed to a linear array of DRAs.*

## 4.5.Analytical Evaluation of Dielectric Resonator Antenna

*In designing, input impedance is the important parameter which is a feed to excite the DRA. Input impedance as a function of frequency is to determine the bandwidth of operation and for matching the antenna to the circuit. Unfortunately, there are no simple closed-form expressions for predicting the input impedance of the DRA when excited by a particular feed and rigorous analytical. Here, some of the techniques that have been used to predict the input impedance for DRAs excited by the various feed*

*.*

### 4.5.1. Green's function analysis

*For a probe-fed DRA, the input impedance (Zin) can be determined using the following equation:*
*(4.1)*
*E= Electric fields of the DRA*
*Js = Applied source current density on the probe*
*IO = Magnitude of the current on the probe*

*The electric fields of the DRA depend on the source excitation and determined by using:*
*(4.2)*
*Here, G represents Green's function for the DRA. By using some simple assumptions about a single-mode operation and the currents on the probe, the Green's function for a hemispherical DRA was first derived and was then used to predict the input impedance of the probe-fed DRA operating in the TE111 mode. This technique was also applied to a probe–fed hemispherical DRA operating in the TM101 mode. The input impedance of conformal strip feeds and aperture feeds can also be analysed using Green's function. The advantage to this technique is the relatively fast computation time required to obtain the input impedance. It is useful method for analysing the effects of altering probe dimensions and probe location and can be used for optimizing the input impedance. The main drawback is its limitation only to hemispherical DRA geometries. For other DRA shapes, different analytical techniques are required [2].*

## 4.5.2.Numerical methods for analysing DRAs

*Numerical methods for analysing DRAs can be categorized into two groups, frequency domain technique and time domain technique. Each category offers advantages for particular antenna geometries [2].*

### 4.5.2.1.Frequency domain analysis

*Two common frequency domain techniques that have been used to analyse DRAs are the method of moments (MOM) and the finite element method (FEM). The MOM was first developed for wire or metal antennas of arbitrary shape, but can be extended to include dielectric materials by introducing equivalent currents. The MOM involves discretizing the antenna into a number of small segments and solving for a set of unknown coefficient representing the current on one segment due to a known incident field. Analysis of DRAs is not limited to a hemispherical shape, and the technique can be used to also analyses simple cylindrical and rectangular DRA shapes. Determining the DRA input impedance using the MOM technique will require more computer memory and time than applying Green's function. Thus, MOM technique is not convenient tool for optimizing the DRA performance. MOM is used to investigate the effect of the air gaps and calculate internal field pattern of various modes of cylindrical DRAs [1], [2].*

*The FEM (Finite element method) can be used to analyses DRAs of arbitrary shape. Similar to the MOM, it involves a discretization of the geometry but whereas in the MOM only the DRA and the ground plane require segmentation , in the FEM the entire volume surrounding the DRA must also be discretized, thereby increasing the computational size of the problem. The advantage of the FEM is that it does not require the formulation of equivalent currents and can thus be readily applied to arbitrary shapes. Another advantage of the FEM is its availability as commercial software where graphical user interfaces are provided to simplify the geometrical definition of the problem. FEM is used to determine the effects of a finite ground plane on the radiation pattern of a DRA [1], [2], [7].*

#### 4.5.2.2.Time domain analysis

*There are two time domain techniques that have been applied to analysing DRAs are the finite difference time domain (FDTD) method and the transmission line method (TLM). These techniques require the entire volume around the DRA to be discretized and thus can be memory and time intensive. In it, wideband pulse used to excite the DRA, and by transforming the solution into the frequency domain, the input impedance can be determined over a wide frequency range. For frequency domain techniques, the problem would have to be re-simulated at each frequency of interest and finding the impedance response over a broad frequency range could be very time consuming. With the frequency domain methods, the time domain methods are good tools for analysing the performance of a given DRA geometry, but are less useful for optimizing the performance of DRAs. FDTD is used to calculate circular polarization patterns of cross-shaped DRAs and input impedance of slot-fed rectangular DRA. Transmission line method used to calculate input impedance of microstrip-fed multi-segment DRAs [1], [2].*