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Dielectric Resonator Antenna and its Design Parameters-A Review

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Abstract*— *This article describes the fundamental concepts and theory of system design for Dielectric Resonator Antenna (DRA). The methodology for designing and simulation of DRA and result analysis of various parameters of the antenna such as return loss, gain, radiation patterns etc. are also explained. The article also discussed the basic algorithms and simulation steps for simulation of DRA using Ansoft High Frequency Structure Simulator (HFSS) software. The method of characterization of the DR and the basic facilities used for the measurement of antenna parameters are also highlighted.

I. INTRODUCTION

A dielectric resonator antenna has a dielectric layer and a conducting layer formed on a main surface of the dielectric layer. An electrical contact is formed on the main surface for connecting the dielectric layer to a transmission line for transferring a signal between the dielectric layer and the transmission line. The electrical contact is insulated from the conducting layer. A conducting strip is connected to the electrical contact and is on a side surface of the dielectric layer. The side surface is not on the same plane of the main surface. Rather, the side surface is perpendicular to the main surface of the dielectric layer. A dielectric resonator antenna (DRA) is a radio antenna mostly used at microwave frequencies and higher, that consists of a block of ceramic material of various shapes, the dielectric resonator, mounted on a metal surface, a ground plane. Radio waves are introduced into the inside of the resonator material from the transmitter circuit and bounce back and forth between the resonator walls, forming standing waves. The walls of the resonator are partially transparent to radio waves, allowing the radio power to radiate into space.[1] An advantage of dielectric resonator antennas is they lack metal parts, which become loss at high frequencies, dissipating energy. So these antennas can have lower losses and be more efficient than metal antennas at high microwave and millimetre wave frequencies. Dielectric waveguide antennas are used in some compact portable wireless devices, and military millimetre-wave radar equipment. The antenna was first proposed by Robert Richtmyer in 1939. In 1982, Long et al. did the first design and test of dielectric resonator antennas considering a leaky waveguide model assuming magnetic conductor model of the dielectric surface. An antenna like effect is achieved by periodic swing of electrons from its capacitive element to the ground plane which behaves like an inductor. The authors further argued that the operation of a dielectric antenna resembles the antenna conceived by Marconi, the only difference is that inductive element is replaced by the dielectric material.

The size of the DRA is proportional to $\lambda_0/\sqrt{\epsilon_r}$ with $\lambda_0 = c/f_0$ being the free-space wavelength at the resonant frequency f_0 and where ε_r denotes the relative permittivity of the material forming the radiating structure. As compared to traditional metallic antennas whose size is proportional to λ_0, DRAs are characterized by a smaller form factor especially when a material with high dielectric constant (ϵ_r) is selected.

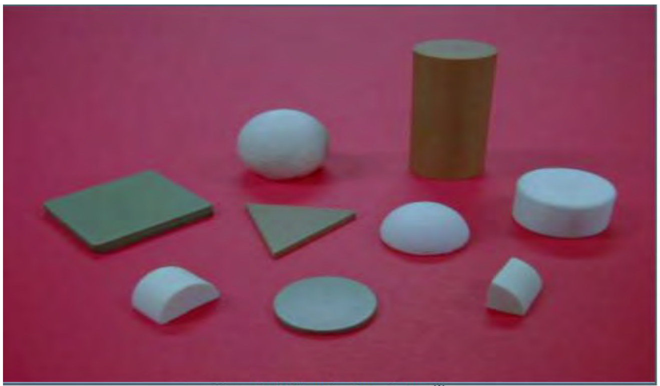

Figure 1. DRAs of various shapes [1]

Due to the absence of conducting material, the DRAs are characterized by high radiation efficiency when a low-loss dielectric material is chosen. This characteristic makes them very suitable for applications at very high frequencies, such as in the range from 30GHz to 300GHz. As a matter of fact, at these frequencies, traditional metallic antennas suffer from higher conductor losses. DRAs can be characterized by a large impedance bandwidth if the dimensions of the resonator and the material dielectric constant are chosen properly. DRAs can be excited using different techniques which is helpful in different applications and for array integration. The gain, bandwidth, and polarization characteristics of a DRA can be easily controlled using different design techniques.

I. Feeding Techniques:

Microstrip patch can be excited either directly or indirectly. Feeding technique influences the input impedance and characteristics of the antenna. It is an important design parameter. Some general feeding arrangements are described below.

1. Microstrip line feed: In this type of feed technique, a conducting strip is connected directly to the edge of the

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Microstrip patch as shown in Figure 2.1. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

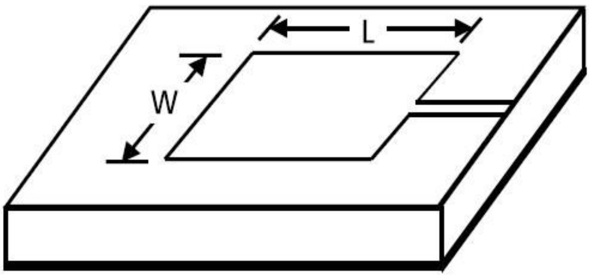


Fig. 2.1. Microstrip line feed.

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna. The feed radiation also leads to undesired cross polarized radiation.

2. Coaxial feed: The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure 2.2, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane.

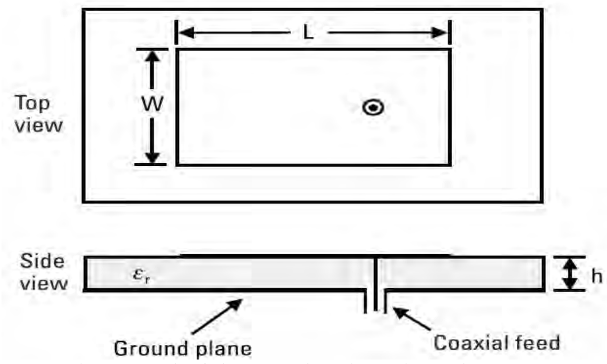


Fig. 2.2. Probe fed rectangular microstrip patch antenna.

The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, a major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda_o$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems. It is seen above that for a thick dielectric substrate, which provides broad bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages. The disadvantages are that the two layers need to be aligned properly. The non-contacting feed techniques which have been discussed below, solve these issues, but that the overall thickness of the antenna increases.

3. Aperture coupled feed: In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 2.3. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

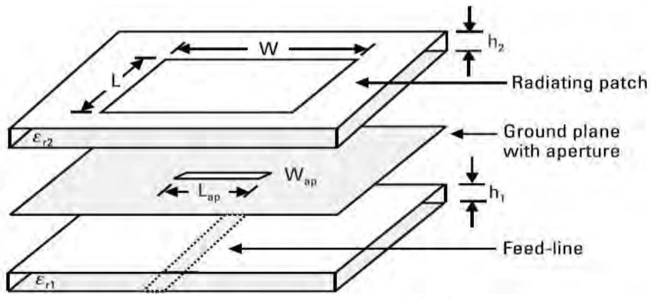


Fig. 2.3. Aperture-coupled feed.

The coupling aperture is usually centred under the patch, leading to lower cross- polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth.

4. Proximity coupled feed: This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 2.4, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%), due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances.

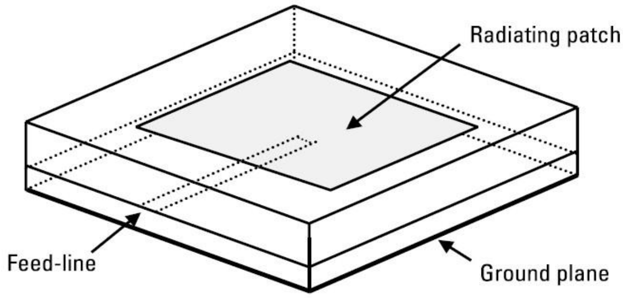


Fig. 2.4. Proximity coupled feed.

Matching can be achieved by controlling the length of the feed line and the width- to-line ratio of the patch. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the antenna.

II. Bandwidth Enhancement Techniques:

Bandwidth can be enhanced by following techniques:
1. Multi-element DRA: By using Multi-element we can improve BW and gain.
2. Multi-segmentation: we can improve BW and gain. Multi segment DRA has following feathers:

- Strong coupling is possible due to high permittivity DR.
- Wide BW is achieved by low permittivity DR.
- In the method high permittivity DR is inserted below low permittivity DR for matching impedance of DRA.
- This technique can enhance the BW up to 20%.

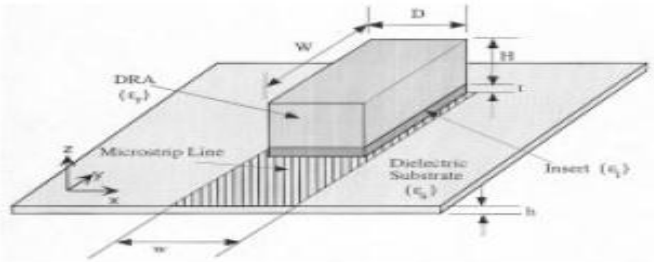


Fig. 4.1. Multi segment DRA.

3. Introducing gap between ground plane and dielectric resonator antenna

- By introducing gap between ground plane and dielectric resonator antenna Q-factor can be efficiently reduced and exhibit a broader bandwidth.
- Bandwidth of around 30% can be obtained.

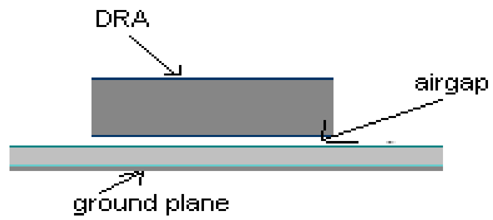


Fig. 4.2. Air gap between ground plane and DRA.

III. Low-Profile and Compact Designs:

Unlike many other resonant antennas, the aspect ratio of most shapes of dielectric resonator antennas can be altered while maintaining the same resonant frequency, for a given dielectric constant. A tall, thin dielectric resonator antenna can thus have the same resonant frequency (but not necessarily the same bandwidth) as a low, wide dielectric resonator antenna. This allows for a certain degree of flexibility in shaping the dielectric resonator antenna to suit specific requirements. This section examines dielectric resonator antennas designed with either a low profile or a compact size, and highlights the achievable bandwidth performance.
1. Low-Profile DRA: For applications needing low antenna profiles, the dielectric resonator antenna can be made very thin, and by using a high dielectric constant, the other dielectric-resonator-antenna dimensions can be kept small. Figure 4.3 shows examples of low-profile dielectric resonator antennas of different shapes. Table I summarizes some of the published lowest-profile dielectric-resonator antenna designs. By choosing values of the dielectric constant in the range $80<\varepsilon_r<100$, the dielectric-resonator-antenna height (h) can be kept in the range $0.025\lambda < h < 0.035\lambda$ while maintaining impedance bandwidths of up to approximately 3.5%.

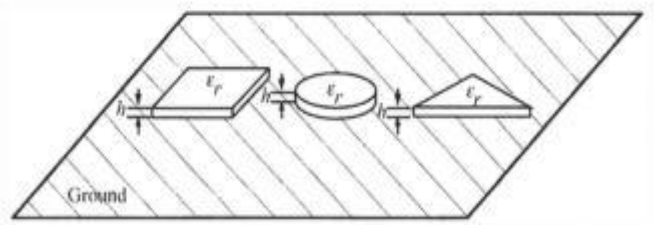


Fig. 4.3. Low-profile dielectric resonator antennas using high dielectric-constant material.

TABLE I. Results of low-profile DRA.

DRA Shape	f_0 (GHz)	ε_r	Maximum Dimension (M)	Height (h)	Aspect Ratio (M/h)	Feed Type	*BW*
Rectangular	7.72	100	$0.327\lambda_0$	$0.026\lambda_0$	12.6	Slot	3.2%
Rectangular	4.57	100	$0.152\lambda_0$	$0.031\lambda_0$	4.9	Slot	1.2%
Rectangular	2.09	79	$0.195\lambda_0$	$0.034\lambda_0$	5.7	Coplanar	2.4%
Cylindrical	4.18	82	$0.174\lambda_0$	$0.028\lambda_0$	6.2	Strip	3.6%
Triangular	7.59	82	$0.506\lambda_0$	$0.028\lambda_0$	18.1	Slot	3.0%
Triangular	8.80	82	$0.587\lambda_0$	$0.029\lambda_0$	20.24	Probe	3.3%

2. Compact DRA: Numerous applications, especially for consumer wireless, require compact antennas to be integrated into small packages, such as cell phones, laptops, or other portable devices. In addition low-profile dielectric resonator antennas using high permittivity makes the antenna compact.

II. DRA CHARACTERISTICS

DRA is characterized by high radiation efficiency, a compact size and a wide operational bandwidth as compared to the other resonating antennas. In addition to that their excited modes, resonance frequencies and radiation characteristics are determined by the geometry, dielectric constant and the coupling mechanisms. This great versatility of the DRA in terms of their shape and feeding scheme in combination with their other advantageous inherent properties make them suitable candidates for many commercial applications. The DRA is an antenna that makes use of a radiating mode of a dielectric resonator (DR). It is a three dimensional element of any shape, e.g. hemispherical, cylindrical, rectangular, triangular etc. Resonance frequency determined by its dimensions and dielectric constant.
1 Antenna radiation patterns: An antenna radiation pattern or antenna pattern is defined as "a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation patterns determined in the far field region and are represented as a function of the directional coordinates.

Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization." The radiation property of most concern is the two- or three dimensional spatial distribution of radiated energy as a function of the observer‟s position along a path.

2. Gain: It‟s another useful measure describing the performance of an antenna.. Although the gain of the antenna is closely related to the directivity, it is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. Gain of an antenna (in a given direction) is defined as "the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically.

3. Directivity: The term directivity is defined as "the ratio of the radiation intensity in a 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 4π. If the direction is not specified, the direction of maximum radiation intensity is implied."

4. Bandwidth: The bandwidth of an antenna is defined as "the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard." The bandwidth can be considered to be the range of frequencies, on either side of a centre frequency (usually the resonance frequency for a dipole), where the antenna characteristics (such as input impedance, pattern, beamwidth, polarization, side lobe level, gain, beam direction, radiation efficiency) are within an acceptable value of those at the centre frequency.

5. Polarization: Polarization is the direction of the electric field and is the same as the physical attitude of the antenna. A vertical antenna will transmit a vertically polarized wave. The receive and transmit antennas need to possess the same polarization

6. Voltage standing wave ratio (VSWR): In order for the antenna to operate efficiently, maximum transfer of power must take place between the transmitter and the antenna. Maximum power transfer can take place only when the impedance of the antenna (*Zin*) is matched to that of the transmitter (*ZS*). According to the maximum power transfer theorem, maximum power can be transferred only if the impedance of the transmitter is a complex conjugate of the impedance of the antenna under consideration and vice-versa. Thus, the condition for matching is, $Z_{in} = Z_s$

Where $Z_{in} = R_{in} + j X_{in}$ and $Z_s = R_s + jX_s$

If the condition for matching is not satisfied, then some of the power may be reflected back and this leads to the creation of standing waves, which can be characterized by a parameter called as the Voltage Standing Wave Ratio (VSWR).

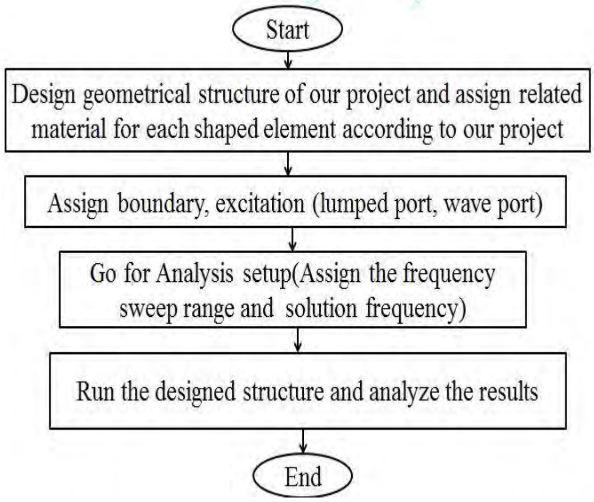
7. Return loss: The Return Loss (RL) is a parameter which indicates the amount of power that is „lost‟ to the load and does not return as a reflection. As explained in the preceding section, waves are reflected leading to the formation of standing waves, when the transmitter and antenna impedance do not match. Hence the RL is a parameter similar to the VSWR to indicate how well the matching between the transmitter and antenna has taken place.

III. Simulation Tool and Algorithem

1. HFSS: HFSS is a high-performance full-wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device modelling that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modelling, and automation in an easy-to-learn environment where solutions to your 3D EM problems are quickly and accurately obtained. It is an interactive software package for calculating the electromagnetic behaviour of a structure.

Ansoft HFSS employs the Finite Element Method (FEM), adaptive meshing, and brilliant graphics to give you unparalleled performance and insight to all of your 3D EM problems. Ansoft HFSS can be used to calculate parameters such as S Parameters, Resonant Frequency, and Fields.

1. Flow Chart for Design a Project in HFSS



2. Algorithm for Design a Project in HFSS

1. Start.
2. Open HFSS software.
3. Insert Geometrical Project design.
4. Assign material for each element of the project.
5. Assign radiation boundary for the Designed structure.
6. Give the excitation (lumped port and wave port) to the designed structure.
7. Go for the analysis setup (assign frequency sweep range and solution frequency).
8. Run the project and analyzed the results.
9. Stop.

Steps to design the conical DRA using HFSS software

1. Create and save the new project:
   - Click file>new
   - A new project is listed in the project manager window
   - The 3-D modular window appear to be right of the project manager you can create the model geometry
2. Drawing different units of the structure:
   - Select the rectangular box from the toolbar for creating the ground assigning proper dimension.
3. Assigning the material:
   - Right click on ground and select „pec‟ material

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4. Inserting prob inside the outer conductor:
   - Designing of coaxial probe for feeding conical DRA
5. Assign Boundary and Ecitation:
   - Take one circle to cover the coaxial feed point so that we can assign the port
   - Assining of port for excitation of coaxial probe
   - Assign radiation boundary
6. Placing conical DRA on the ground plane
7. Analysis setup
   - Select the menu item HFSS>analysis setup>add solution setup
   - In the solution setup window, click the general tab, solution frequency 5.1 GHz
   - Maximum number of passes is 10
8. Adding frequency sweep
   - To add a frequency sweep, select the menu items HFSS >analysis setup>add sweep
   - Select solution setup setup1 click ok button then edit sweep window
   - sweep type fast
   - frequency setup type: linear count
   - start:3GHz
   - stop:8GHz
   - steps:0.05 GHz click ok button
9. Validation and simulation:
10. Results:
    - Return loss Vs Frequency
    - Radiation pattern:

IV. Advantages and Application

1. Advantages of DRAs: DRAs offer a high degree of flexibility and versatility over a wide frequency range, allowing for designers to suit many requirements. DRAs offer the following advantages:

- DRAs come in simple geometries like circular cylinder; hemisphere, rectangular etc. are readily available and can be easily fabricated.
- In DRA for the same frequency there is a natural reduction in size, compared with their conventional counterparts like microstrip antennas. Also, different values of ε_r (ranging from 4 to 100) can be used, thus allowing the designer the flexibility in controlling the size and bandwidth.
- Depending on the resonator shape, various modes can be excited within the DRA element. These modes can produce different radiation patterns for various coverage requirements. Also, the Q-factor of some of these modes will depend on the aspect ratio of the DRA, thus allowing one more degree of flexibility in the design.
- Many of the existing feeding schemes can be used (slots, probes, microstrip, coplanar waveguides, dielectric image guide, etc.). This makes them easy to integrate with existing technologies.
- Compared with the microstrip antenna, DRA has a much wider impedance bandwidth. This is because the microstrip antenna radiates only through two narrow radiation slots, whereas the DRA radiates through the whole antenna surface except the grounded part. Moreover the operating bandwidth of a DRA can be varied by suitably choosing the dielectric constant of the resonator material and its dimensions.
- DRAs have been designed to operate over a wide frequency range (1 GHz to 44 GHz) compared with other antennas existing in the literature.
- DRAs have a high dielectric strength and hence higher power handling capacity. Moreover the temperature-stable ceramics enable the antenna to operate in a wide temperature range.
- There is no inherent conductor loss for a DRA, So a High radiation efficiency.

2. Applications:

- Attractive for conformal applications, such as mobile satellite communications.
- The high efficiencies make DRAs suitable candidates for millimeters-wave arrays.
- Mobile phone handsets.
- Laptops.
- PDAs.

V. Conclusion

Thus the article explains the basic theory and system design for Dielectric Resonator Antenna. The different feeding techniques and bandwidth enhancement techniques for DRA was discussed in this article. The article explains the basic algorithm and steps for simulation of DRA by using Ansoft High Frequency Structural Simulator (HFSS) software. It concludes the basic system design and analysis of DRA. The Article also explains the result analysis of various parameters of the antenna results such as return loss, gain, radiation patterns etc.

Reference

[1] Petosa, *Dielectric Resonator Antennas Handbook*, Artech house publishers, Jan 31, 2007.
[2] K. L. Wong, *Planar Antennas for Wireless Communication*, John Wiley & Sons, USA 2003.
[3] K. M. Luk and K. W. Leung, *Dielectric Resonator Antennas*, Research Studies Press, Hertfordshire, U.K., 2003.
[4] A. Petosa, A. Ittipiboon, Y. M. M. Antar, D. Roscoe, and M. Cuhaci, "Recent advances in dielectric-resonator antenna technology," *Antennas & Propagat. Mag*., pp. 35–48, June 1998.
[5] R. K. Mongia and A. Ittipiboon, "Theoretical and experimental investigations on rectangular dielectric resonator antennas," *IEEE Transactions on Antenna and Propagation*, Vol. AP-45, pp. 1348-1356, 1997.
[6] M. W. McAllister, S. A. Long and G. L. Conway, "Rectangular dielectric resonator antenna," *Electronics Letters*, vol. 19, pp. 218-219, 1983.
[7] R. K. Mongia, "Theoretical and experimental resonance frequencies of rectangular dielectric resonators," *IEEE Proc. Pt-H*, vol. 139, pp. 98-104, 1992.
[8] R. K. Mongia, A. Ittipiboon, and M. Cuhaci, "Low profile dielectric resonator antenna using a very high permittivity material," *Electron. Lett*., vol. 30, no. 17, pp. 1362-1363, Nov. 1993.
[9] M. S. M. Aras, M. K. A. Rahim, A. Asrokin, M. Z. A. Abdul Aziz, "Dielectric Resonator Antenna (DRA) for wireless application," *IEEE International RF and Microwave Conference Proceedings*, pp. 454–458, December 2-4, 2008, Kuala Lumpur, Malaysia.

[10] P. Mahender, S. Natarajamani and S. K. Behera, "Inverted V-Shaped dielectric resonator antenna for WLAN," *IEEE ICCCCT-10*, pp. 9-11, 2010.
[11] P. Rezaei M. Hakkak and K, Forooraghi "Dielectric resonator antenna for WLAN applications," *IEEE Antennas and Propagation Society Symposium*, vol. 2, pp. 1005-1008, July 2006.
[12] Ravi Kumar Gangwar, S. P. Singh, D. Kumar, "Four element wideband rectangular dielectric resonator antenna terminated in bio-midium," *Wireless Pers Commun*, DOI 10.1007/S 11277-013-1209-6, May, 2013.
[13] Raghvendra Kumar Chaudhary, Kumar Vaibhav Srivastava, and Animesh Biswas, "Wideband multilayer multi-permittivity half-split cylindrical dielectric resonator antenna," *Microwave and optical Technology letters*, vol. 54, no. 11 , pp. 2587-2590, Nov. 2012.
[14] Vipul Ranjan Kaushik, "Metal loaded low profile and compact dielectric resonator antenna for WiMAX/WLAN applications," *Journal for Advanced Research in Applied Sciences*, vol. 4, issue 4, pp. 34-37, Sept-2017.