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A Review on Dielectric Resonator Antennas

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Abstract – **This paper describes the study of simulation of Dielectric Resonator Antenna (DRA) in rectangular shape for various wireless based applications. Variety of Rectangular Dielectric Resonator Antennas (RDRA) is discussed in this paper. RDRAs are extensively used in WiMAX, WLAN and Wi-Fi applications with different substrates and feed techniques. This paper thoroughly discusses the characteristics, merits and applications of DRA.**

Keywords: **DRA, RDRA, WiMAX, WLAN, Wi-Fi, CST microwave studio**.

I. INTRODUCTION

When a Dielectric Resonator (DR) is not completely enclosed by a conducting boundary, it can radiate .i.e. it acts as an antenna, termed as DRA. Its resonance frequency is a function of size, shape and permittivity. DRAs are much significance because of their small size, light weight and low cost. DRAs offer high radiation efficiency, flexible feed ,compactness and geometry[1]-[4].Further, different feeding methods can be used to excite DRAs, such as, co-axial probe[5], micro strip feed line [6],an aperture coupled source[7] and a coplanar wave guide(CPW)[8].The inherent advantage of DRA is that they can achieve wide band width and high radiation efficiency. DRAs can be designed in different shapes like cylindrical, hemispherical, elliptical, pyramidal, rectangular and triangular. Rectangular shape DRAs have much significant over other shapes due to its design flexibility[9].In the last decade different DR structures [10]-[17],such as embedded DR, Tetra Hadrian, L shaped ,T shaped, Stair shaped, trapezoidal shaped are developed for band width enhancement.

II. DRA DESIGN

The basic dimensions of DRA can be obtained in two different modes like Dielectric Wave guide Model (DWM)[18] and Magnetic Wall Wave guide mode (MWM)[19].Assuming MWM at the surface of the resonator, the following equations are obtained for wave numbers and for resonance frequency for dominant mode (TE to Z mode)

$$f_r = \frac{1}{2\sqrt{\epsilon\mu}}\sqrt{\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2 + \left(\frac{p}{h}\right)^2} \qquad (1)$$

where $m = n = p = 1$ and

$\epsilon =$ permittivity of the material in transverse plane (X-Z)

$\mu =$ permeability of the material

$L, W, h =$ Length, Width and Height of the resonator .

Dimensions of Dielectric resonator can be obtained from the following equations

$$k_0 = \frac{2\pi f_r}{c} \quad (2)$$

$k_0 =$ Wave number in free space

$c = 3 \times 10^8 m/s =$ Velocity of light

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \quad (3)$$

$$k_x = \frac{m\pi}{L}, k_y = \frac{n\pi}{W} \ and \ k_z = \frac{p\pi}{2h}$$

$k_x, k_y, k_z =$ Wave numbers along x, y and z directions of resonator.

dielectric resonator must satisfy the condition

$$k_z \tan\left(\frac{k_z h}{2}\right) = \sqrt{(\varepsilon_r - 1)k_0^2 - k_z^2} \quad (4)$$

when $\frac{W}{h} < 1$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\left(1 + 12\left(\frac{h}{W}\right)\right)^{-1/2} + 0.04\left[1 - \left(\frac{W}{h}\right)^2\right]\right] \quad (5)$$

when $\frac{W}{h} \geq 1$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\left(1 + 12\left(\frac{h}{W}\right)\right)^{-1/2}\right] \quad (6)$$

slot dimensions

$$L_s = \frac{0.4\lambda_r}{\sqrt{\varepsilon_e}} \quad (7)$$

$$\varepsilon_e = \frac{\varepsilon_r + \varepsilon_s}{2} \quad (8)$$

$\varepsilon_r, \varepsilon_s =$ Dielectric constant of RDR and substrate

$$W_s = 0.2\, L_s \quad (9)$$

stub length $L = \frac{\lambda_g}{4}$ (10)

$\lambda_g =$ Guided wave length in substrate

Micro strip line length and width is given by

$X_f = \frac{L}{2\sqrt{\varepsilon_e}}$ *and* $Y_f = \frac{W_s}{2}$ (11)

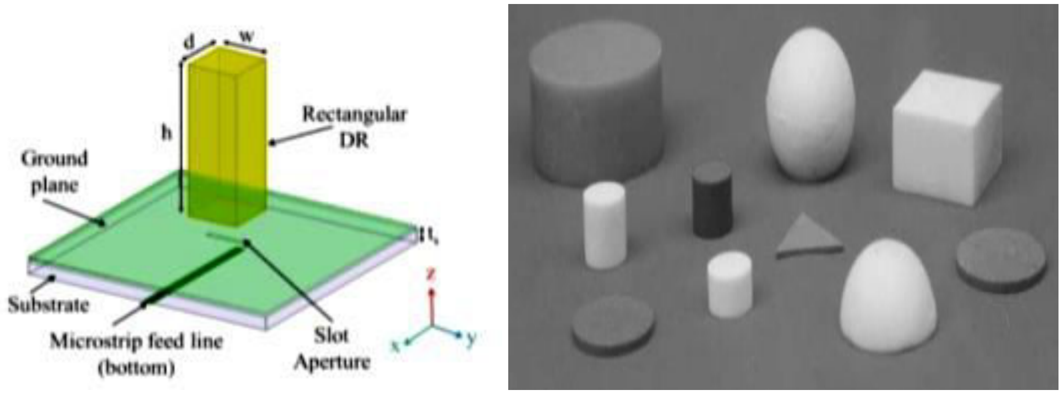

Fig.1 Geometry of DRA & DRAs in different shape

III. LITERATURE SURVEY

Ravi Kumar Gangwar et al [18] have designed a RDRA in C band using co-axial probe and micro strip line feed with the aid of finite integration method (FIM) (CST micro wave studio) and Finite element method (FEM) (Ansoft HFSS).In probe feed method maximum coupling and wide band width is achieved on error and trial method varying probe length and probe position from the antenna. In micro strip line feed maximum coupling and wide band width is achieved when RDRA is placed at a $\frac{\lambda}{2}$ distance from the open end and strip length $\Delta L = 4.1mm$.FEM is showing more accurate result over (FIM) interims of directivity, gain, radiation efficiency, total efficiency,3 dB beam width and cross polarization.

mohsen Khalily et al [19] have designed a P shaped DRA for wide band wireless applications. This antenna covers wireless systems like WLAN and WiMAX (C band 5.2,5.5 and 5.8 GHz).In this work they are carried a parametric study(using CST micro wave studio) to improve return loss, which is useful to realize an antenna .In this work they have introduced a hole in different shapes in DR to reduce effective permittivity of the whole DR volume, which consequently reduce radiation Q factor of DR and thus increase impedance bandwidth. Highest band width (6.8 to 13 GHz .i.e. 62 %) is obtained when trapezoidal shaped hole is introduced.

Ravi Kumar Gangwar et al [20] have designed segment rectangular dielectric resonant antenna (DSRDRA) in free space and in presence of bio medium. The simulation results such as return loss, VSWR, band width of DSRDRA (free space) are compared with when DSRDRA is in direct contact with homogeneous bio medium(muscle layer).It is observed from simulation results that the SAR value increases with increase in frequency and when antenna is getting closed to bio medium .Penetration depth and transverse plane resolution in bio medium is increasing with reduction in frequency .

H Roggad et al [21] have designed a dual band DRA fed by a micro strip line. In this design both fundamental TE_{111} and higher order TE_{113}propagation modes are excited. The resonant frequency of $TE_{111}$and TE_{113} modes are adjusted by varying the dimensions of the DRA. This antenna is suitable for digital communication system (1710 - 1880 MHz) and WLAN (2400- 2484 MHz) applications. This antenna has shown good directional radiation pattern for both the resonating frequencies. This design is a good choice for new communication system requirements.

IV. FEEDING METHODS

Feeding techniques are required to energize the antenna i.e. to transfer the power into the antenna. Early micro strip antennas were fed either by a micro strip line or a coaxial probe through the ground plane. Dielectric resonator antennas have radiating elements on one side of dielectric substrate and for these designs a number of new feeding techniques have been developed [22], [23]. Some feeding techniques are easy to fabricate where as other are difficult, and some feeding techniques can enhance the bandwidth. For example, aperture and proximity feeds are used to increase the bandwidth but fabrication is the major problem because these two feeding techniques useful when two substrate are present.

A. Micro strip feed

Excitation of the dielectric resonator antenna by a micro strip line on the same substrate is the easiest method of feeding. In this type of feed technique, a conducting strip is connected directly to the edge of the dielectric resonator (DR) or inserted under the DR. A common method of excitation with micro strip line is to use it by proximity coupling. The amount of coupling from the micro strip line to the DRA can be controlled to a certain degree by adjusting the spacing between the DRA and the line for the side-coupled case or the length of the line underneath the DRA for the direct-coupled case [22]. The dielectric constant of the DRA also affects the coupling. Higher the value of dielectric constant, higher will be the value of the coupling. This is an easy feeding scheme and it provides ease of fabrication and simplicity in modeling as well as impedance matching. As the thickness of the dielectric substrate of the DRA increases, surface waves and spurious feed radiation also increase, so the thickness of the substrate should be kept less [22]-[25]. Fig.2 shows the micro strip feed technique to DRA.

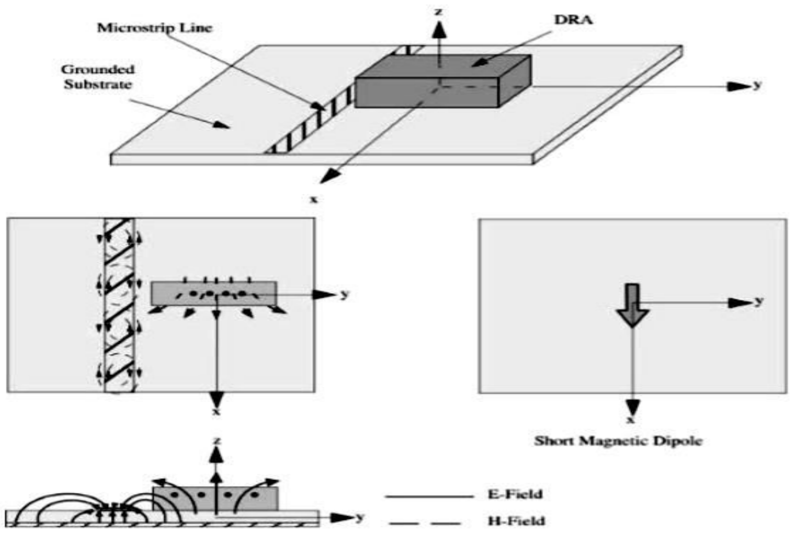

Fig. 2 micro strip line feed

B. Coaxial / probe feed

Another common method of coupling to DRA is with a probe. The probe usually consists of the center pin of a coaxial transmission line that extends through the ground plane. The center pin can also be soldered to a flat metal strip that is placed adjacent to the DRA, whose length and width can be adjusted to improve the impedance match [26], [27]. The coaxial connector is attached to the back side of the DRA and the coaxial center conductor after passing through the substrate is drilled into the dielectric resonators. The amount of coupling can be controlled by adjusting the probe height and the DRA location. The probe length is generally chosen to be less than the height of the DRA, to avoid probe radiation. Feeding the probe adjacent to the DRA is preferred since it does not require drilling into the DRA. The advantage of the coaxial probe excitation is the direct coupling into a 50-Ω system without the need for a matching network [26], [27]. Fig.3 shows the probe coupling to the DRA.

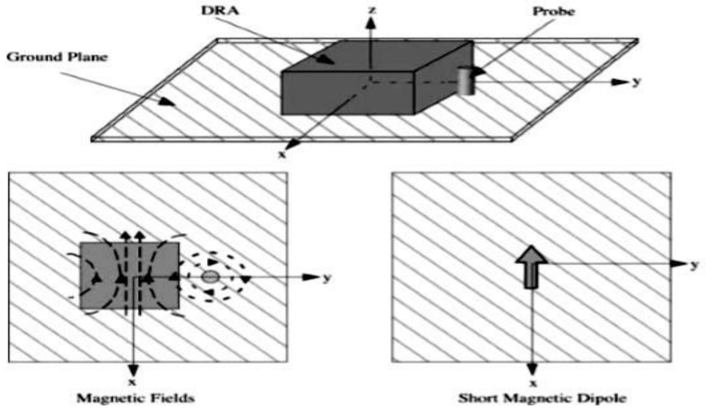

Fig. 3 Probe feed

C. Aperture feed

One common method of exciting a DRA is through an aperture in the ground plane upon which the DRA is placed. Small rectangular slot is the most widely used aperture [22], [23], [28]. By keeping the slot dimensions electrically small, the amount of radiation beneath the ground plane can be minimized. Annular slots are generally used for exciting cylindrical DRAs, while cross shaped and C-shaped slots are used to excite circular polarization. The aperture can be fed by a transmission line (either micro strip or coaxial) or a waveguide. Aperture coupling offers the advantage of having the feed network located below the ground plane, isolating the radiating aperture from any unwanted coupling or spurious radiation from the feed [22]. Feeding the aperture with a micro strip transmission line is the most common approach, since printed technology is easy to fabricate. Micro strip line also offers a degree of impedance matching not available with coaxial lines or waveguides [29]-[31]. Fig.4 shows the aperture coupling to the DRA.

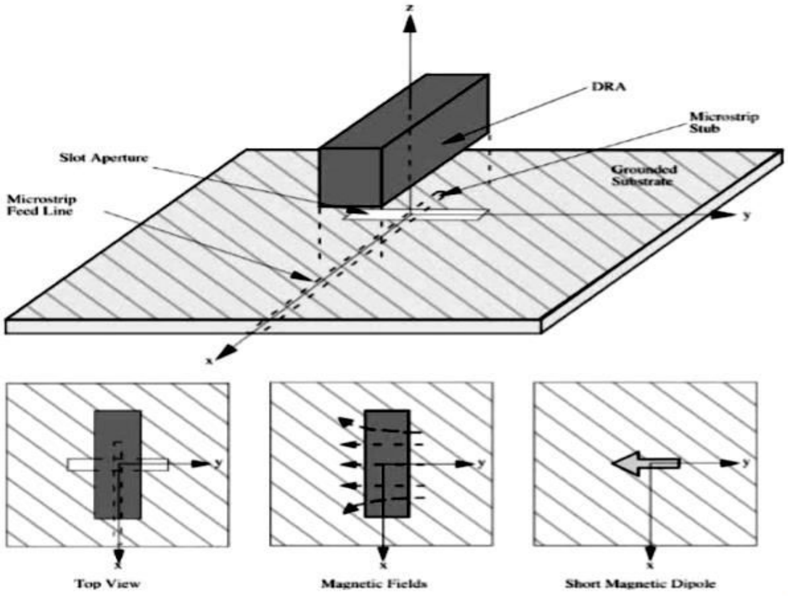

Fig. 4 Aperture feed

D. Proximity coupled micro strip feed

In this type of feeding we use a two layer substrate and the DRA is placed on the upper layer. This feed is also known as an electromagnetically coupled feed. To design this feed Two substrates are required, and the feed line should be in between the two substrates. The fabrication of the antenna is difficult and the thickness of the antenna is increased due to the presence of two substrates. By using this feeding technique The bandwidth of the antenna can be improved. The substrate parameters of the two layers can be selected to increase the bandwidth and to reduce spurious radiation, for this the lower substrate should be kept thin [32], [33].

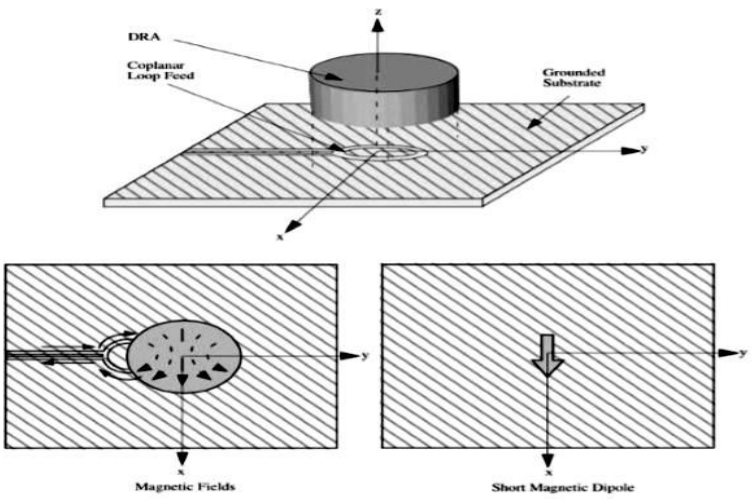

Fig. 5 Coupled feed

Some advantages are:

- No physical contact between feed line and radiating element
- No drilling required.
- Less spurious radiation.
- Better for array configurations.
- Good suppression of higher order modes
- Better high frequency performance

E. Coplanar feed

Coupling to DRAs can also be achieved by using coplanar feeds. Open-circuited waveguides can be used to directly feed the DRAs. Additional control for impedance matching can be achieved by adding stubs or loops by the end of the line. Fig.5 shows a cylindrical DRA coupled to a coplanar loop. The coupling level can be increase or decrease by positioning the DRA over the loop and by moving the loop from the edge of the DRA to the center. The dimensions of the coplanar feed should be chosen large enough to ensure proper coupling, but small enough to avoid excessive radiation in the back lobe [32], [33]. The coupling behavior of the co-planar loop is similar to coaxial probe, but the loop offers the advantage of being non-obtrusive.

F. Dielectric image guide feed

This coupling technique is similar to micro strip line coupling, but instead of perfect electric conductor we use dielectric material as feed line. Dielectric image guides offer advantages over micro strips at millimeter-wave frequencies, since they do not suffer from conductor losses. The coupling can be controlled by adjusting the spacing between the guide and the DRs [22], [23], [18], [25]. Fig.6 shows the dielectric image guide coupling of the DRA.

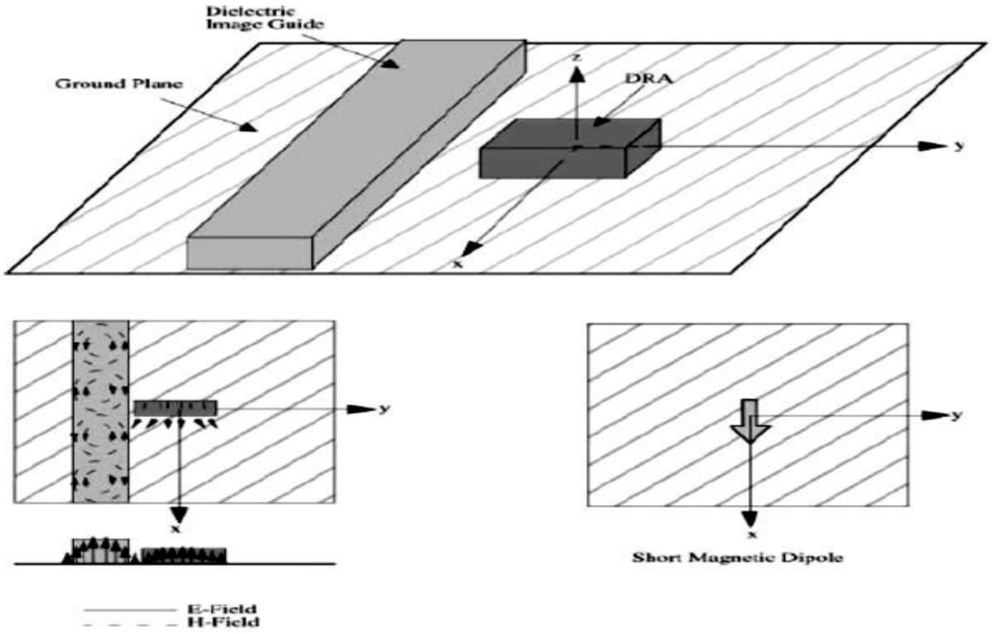

Fig. 6 Dielectric image guide feed

V. CHARACTERISTICS OF DRA

Some of the main characteristics of the dielectric resonator antennas are summarized below;

- The size of the DRA is proportional to $\frac{\lambda_0}{\sqrt{\varepsilon_r}}$, where is the free space wavelength at the resonant frequency, and εr is the dielectric constant of the material.
- The resonant frequency and radiation Q-factor is also affected by the aspect ratio of the DRA for a fixed dielectric constant, permitting additional design flexibility to the designers.
- A wide range of dielectric constants can be used allowing the designers to control the physical size and the bandwidth of the DRA.
- By selecting a dielectric material with low loss characteristics, a high radiation efficiency can be maintained in DRAs.
- DRAs can be designed to operate over a wide range of frequencies from 1 GHz to 44 GHz.
- DRA has much wider impedance bandwidth compared to micro strip antennas.
- Depending upon the resonator shape, various modes can be excited within the DRA producing either broad side or Omni directional radiation patterns for different coverage requirements.
- DRAs have high dielectric strength and hence higher power handling capacity.

- It has high degree of flexibility and versatility, allowing for designers to suit a wide range of physical or electrical requirements of varied communication applications.
- Several feeding methods can be used to efficiently excite the DRAs, such as probes, micro strip lines, slots & dielectric image guides & co-planar wave guide lines [22], [23].

VI. LIMITATIONS

- The fabrication price is more as compared to microstrip antenna.
- Ceramic materials are typically used, which must either be machined from large blocks or cast from molds. Drilling may be required and the DRA has to be bonded to a ground plane or substrate.
- Compared to the printed circuit antennas, the fabrication is generally more complex and more costly, especially for array applications.
- Difficult to get dielectric materials of desired dielectric constants, so have to work with limited available sources.
- Excitation of surface waves [22], [23].

VII. APPLICATIONS

- Satellite communication, direct broadcast services.
- Doppler and other radars.
- Missiles and telemetry.
- Mobile radio (pagers, telephones, man pack systems).
- Biomedical radiators and intruder alarms.

VIII. CONCLUSION

This paper thoroughly discussed the work already done in the area of DRAs. After referring large number of research papers it is observed that by properly selecting the shape of DRA it is possible to improve the band width. Following methods are very important for enhancing the performance of DRAs

- Optimizing the feed mechanisms and DRA parameters
- Stub matching (modified feed geometries)
- Altering the shape of DRA
- Using array of DRAs
- Introducing an air gap between the ground and DR
- Changing dielectric constant of DR

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