Lecture 11

Topic:

Dielectric Resonator Antennas: Fundamentals and Applications

Qingsha Cheng

Southern University of Science and Technology (SUSTech), Shenzhen, China

OUTLINE

- Introduction
- History of Development of DRA
- Why DRA
- Fundamentals of DRA
- Design Principles
- Performance Improvement Techniques
- Advantages and Disadvantages
- Future Scope
- Conclusions

INTRODUCTION

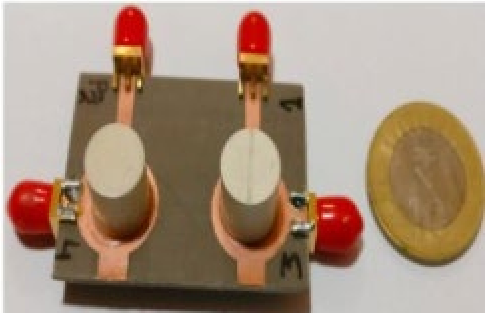
- communication frequency goes up into mm Wave or even higher frequency
- most of the currently used microwave antennas not ideal for higher frequency because of **conduction losses** and **lower efficiency**.

➢ **DRA** is a suitable alternative

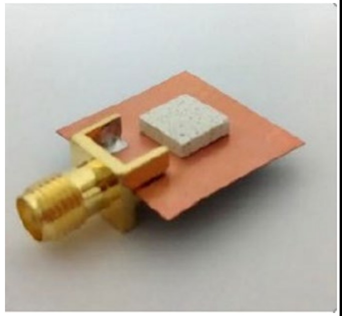
➢ The **DRA** was First proposed by Long *et al.* [3] in 1983.

➢ It's simple **Dielectric** + **Resonator** + **Antenna**

- Sometimes known as DR Antenna
- A Dielectric Resonator, which acts as an Antenna known as DRA.
- Technically we can say, a DRA is a radio antenna mostly used at microwave and higher frequencies, that consists of ceramic material mounted on a metal surface i.e. the ground plane [1-3]

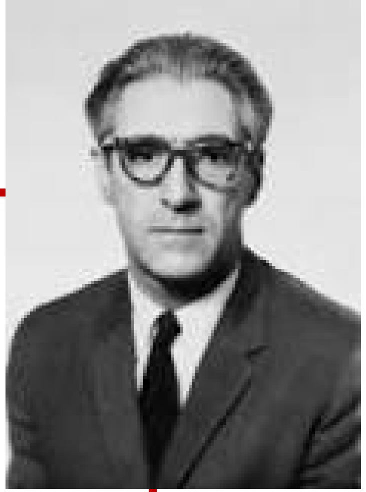


Four port MIMO DRA



Rectangular DRA

INTRODUCTION



- RD Richtmyer [2] published in Journal of *Applied Physics*, in 1939

Dielectric Resonators

R. D. Richtmyer
Stanford University, California
(Received December 14, 1938)

We show that suitably shaped objects made of a dielectric material can function as electrical resonators for high frequency oscillations. We develop the theory of such resonators very briefly and compute their resonant frequencies and losses in some very simple cases. The paper concludes with an observation on the behavior of dielectric wave guides.

1. General Discussion

It was shown by Rayleigh[1] that an "infinitely" long cylinder of a dielectric material can serve as a guide for electromagnetic waves of certain frequencies. That means that the dielectric has the effect of causing the electromagnetic field (except for a small part which decreases exponentially with increasing distance from the cylinder) to be *confined* to the cylinder itself and the immediately surrounding region of space. More recently Southworth and collaborators[2] at the Bell Telephone Laboratories have studied the properties of such wave guides from the point of view of electrical communication.

On the basis of this phenomenon W. W. [...]tially correct, although a slight modification is required. If the part of the field outside of the resonator could decrease exponentially with increasing distance from the resonator, and continue to do so as the distance is increased indefinitely, there could be no loss of energy by radiation, and neglecting dielectric losses oscillations once set up would continue indefinitely. However we shall see that according to the laws of electrodynamics the field *cannot* decrease in quite the manner required, and that it is in fact impossible to confine electromagnetic waves to a finite region of space with the aid of dielectric material alone. Nevertheless in certain cases the energy will escape only very slowly, so that the resonator will exhibit only slightly damped oscil

INTRODUCTION

- SA Long, MW Mcallister, and LC Shen [3] published in *IEEE Transactions on Antennas and Propagation*, in 1983.

406 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. AP-31, NO. 3, MAY 1983

The Resonant Cylindrical Dielectric Cavity Antenna

STUART A. LONG, SENIOR MEMBER, IEEE, MARK W. McALLISTER, AND LIANG C. SHEN, SENIOR MEMBER, IEEE

Abstract—An experimental investigation of the radiation and circuit properties of a resonant cylindrical dielectric cavity antenna has been undertaken. The radiation patterns and input impedance have been measured for structures of various geometrical aspect ratios, dielectric constants, and sizes of coaxial feed probes. A simple theory utilizing the magnetic wall boundary condition is shown to correlate well with meas-ured results for radiation patterns and resonant frequencies.

loss characteristics are utilized. Control of the radiated fields may also prove to be simpler with the main lobe of radiation remaining normal to the ground plane of the structure with variations in geometry and frequency. In addition, circular polarization can probably be obtained by slight changes in geometry in much the same fashion as has been previously accomplished with printed

Dr. Stuart A. Long,
IEEE Life Fellow,
University of Houston

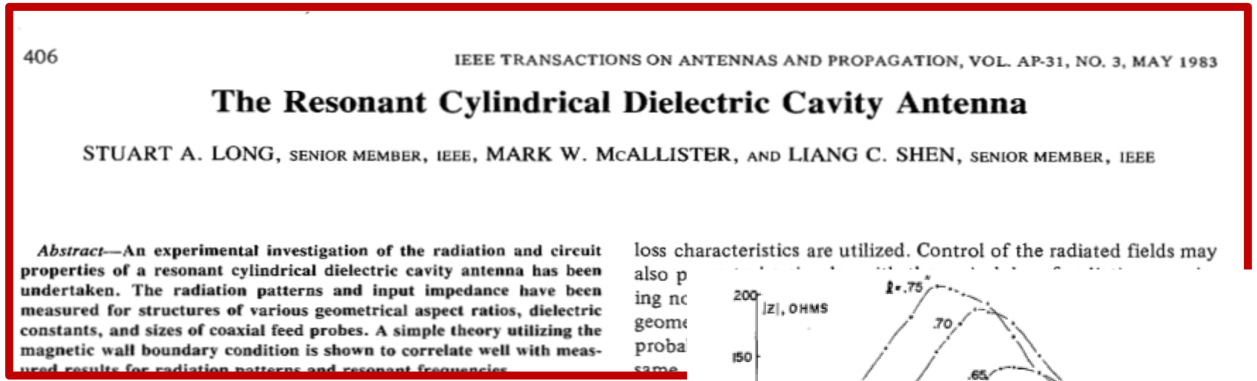
economical fabrication.

A novel structure which seemingly has the possibility of radiating efficiently in this frequency range is the resonant cylindrical dielectric cavity antenna. Previously dielectric cylinders of very high permittivity (relative dielectric constants of the order of 100-300) have been used as resonant cavities [1]-[6]. Theoretical studies of the dielectric cavity have been previously reported by Van Bladel [7], [8]. In each case the emphasis of the investigation has been on the structure as an energy storage device, but since the cavity is not enclosed by metallic walls, electromagnetic fields do exist beyond the geometrical boundary of the cavity. Little or no work has been devoted to this structure as a radiator, nor has a complete investigation of the external fields been made. With the use of lower dielectric constant materials ($5 \leqslant \epsilon_r \leqslant 20$), and proper choices of the dimensions of the cylinder, these radiation fields can be enhanced.

Experimental measurements have been made on several dielectric cylinders with varying geometrical aspect ratios, dielectric constants, and feed probe lengths. This work indicates that such an antenna can be designed to provide reasonably efficient radiation in the direction normal to the ground plane of the antenna. A simple theory utilizing the magnetic wall boundary condition is shown to correlate well with measured results for radiation patterns and resonant frequencies.

INTRODUCTION

- SA Long, MW Mcallister, and LC Shen [3] published in *IEEE Transactions on Antennas and Propagation*, in 1983.



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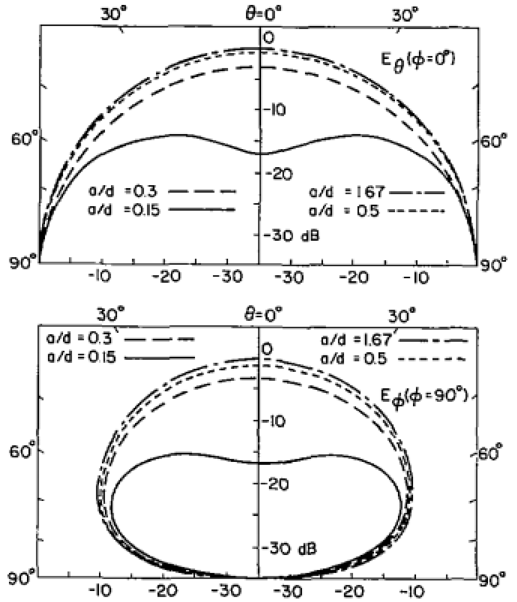


Fig. 2. Theoretical radiation patterns for various a/d ratios.

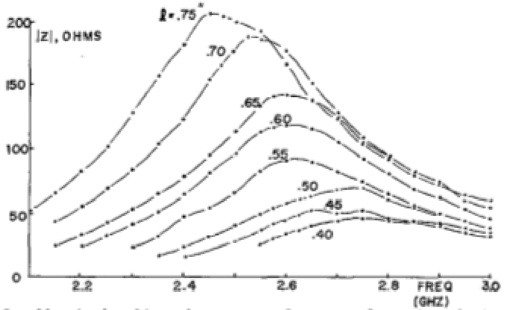
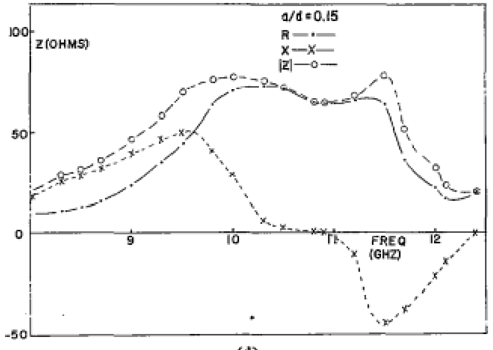


Fig. 8. Magnitude of impedance versus frequency for various feed probe lengths (in inches): $\epsilon_r = 8.9$; $a/d = 0.5$; $a = 0.0127$ m.



(d)

Fig. 5. Measured impedance versus frequency for various a/d ratios; $\epsilon_r = 8.9$. (a) $a/d = 0.3$. (b) $a/d = 0.5$. (c) $a/d = 1.67$. (d) $a/d = 0.15$.

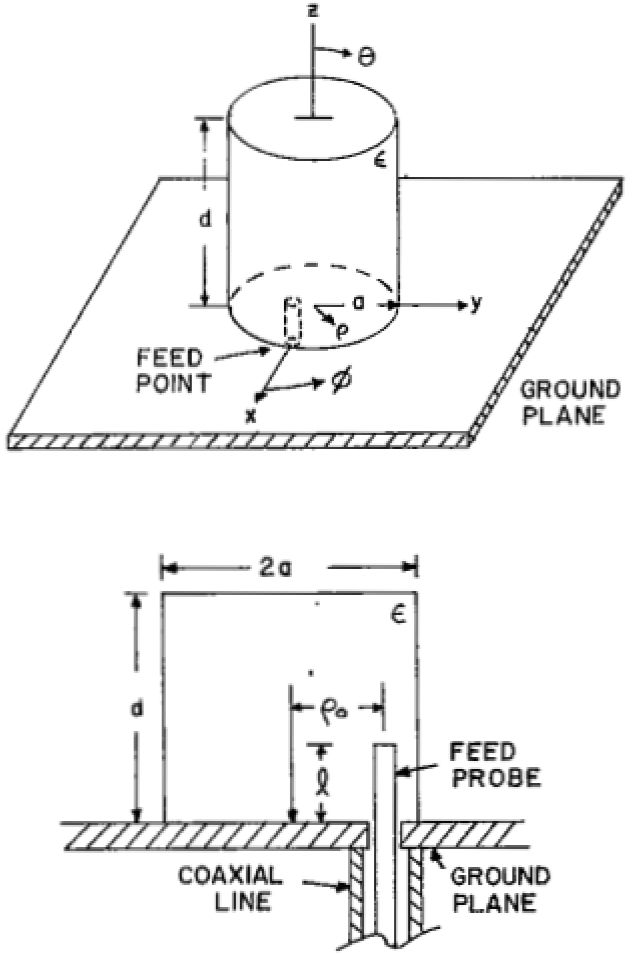


Fig. 1. Antenna geometry and feed configuration.

HISTORY OF DEVELOPMENT OF DRA

1

1939: Ritchmyer [1]
Introduced DR (High Q-factor non metallic resonator)
Applicable for filter or oscillator
Q = Energy Stored / Power Radiated

.
.
No such report in these 20 Years
.
.

2

1960: Okaya and Barash [4], [5]
Investigated DR in the form of single crystal TiO_2

3

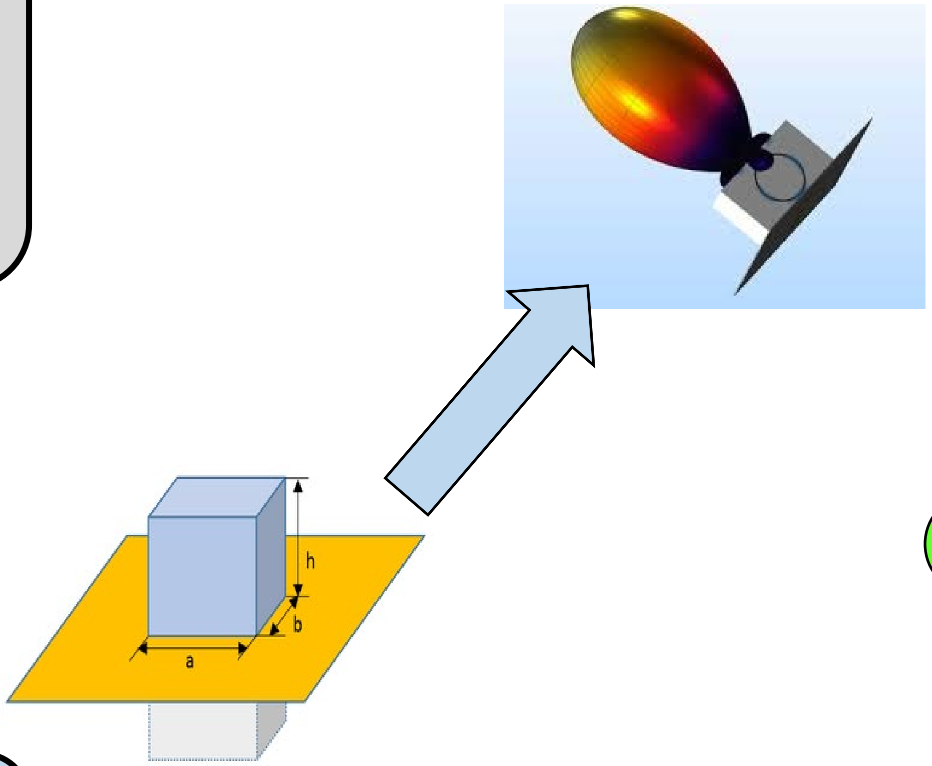
Mid of 1960: Cohn [6]
Extensive theoretical and experimental examination of DR for filters

4

Mid of 1975: Bladel [7], [8]
Detailed the theory for evaluation of DR mode(s)

5

1983: Long et al. [3]
When a DR (of low Q-factor) is placed on a metallic ground with unshielded surroundings and given excitation, radio waves radiate into the space



WHY DRA ?

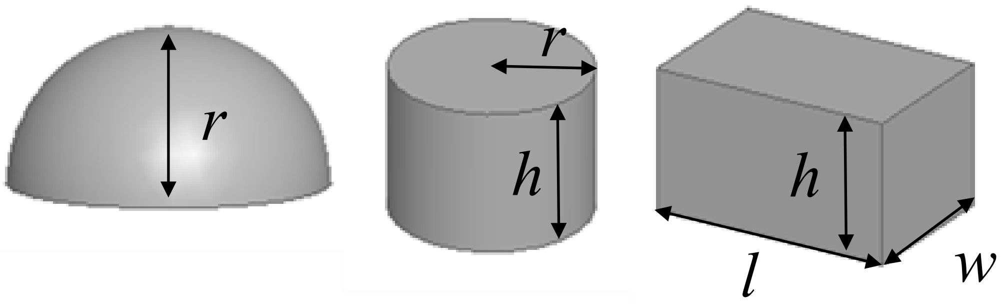
Advantages

Flexibility in Modeling/Design:

- More degrees of freedom (in dimension)
  - Hemisphere (1 variable)
  - Cylinder (2 variables)
  - Rectangle (3 variables)
- More degrees of freedom (in permittivity)
- Multiple feeding mechanism

Advanced Performance characteristics:

- Wider bandwidth
- No conduction loss
- Supports several radiating modes
- Higher efficiency
- Maintenance free



FUNDAMENTALS OF DRA

❑ Performance Features of DRA:

- **Wide range of bandwidth** w.r.t. resonator parameters.

  It can be **a few percent with high ε_r** material

  or

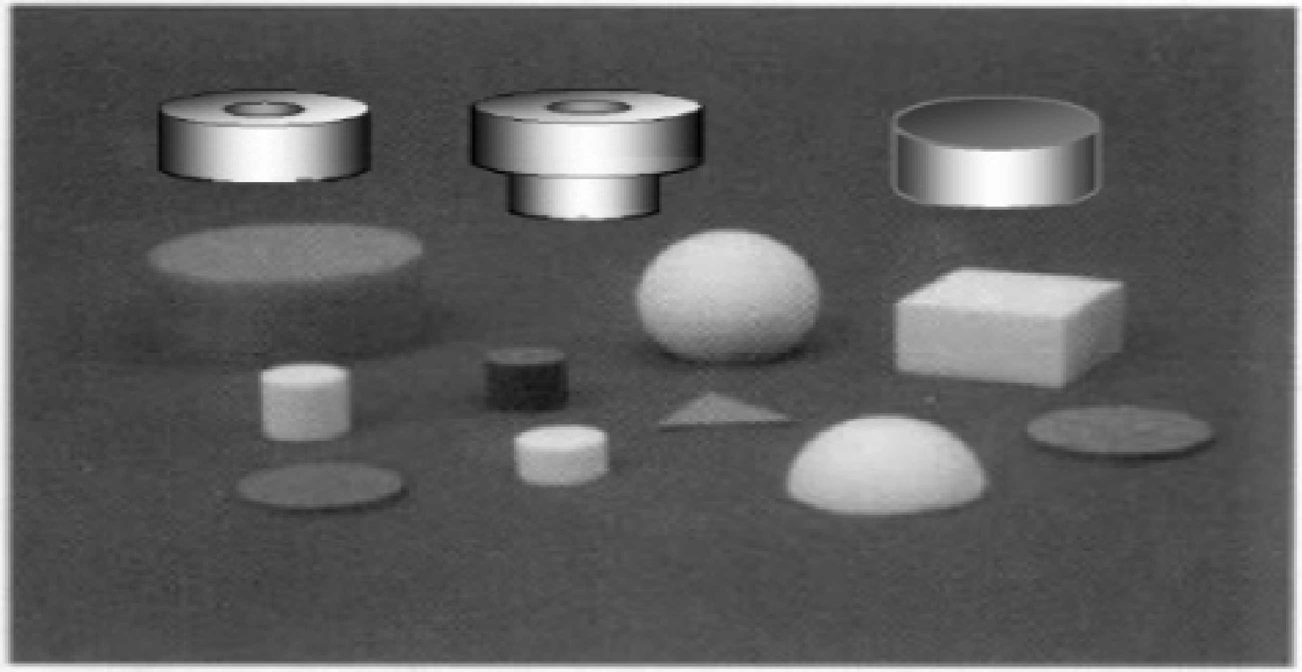
  over 20% with small ε_r in certain geometries and multi-resonant modes.

- **Different far field radiation patterns** are supported. Can be controlled by exciting different resonant modes
- **Less susceptible to tolerance errors** as microstrip antennas, especially at higher frequencies.

FUNDAMENTALS OF DRA

❑ Performance Features of DRA:

- RA can be integrable with MMIC circuits due to small size.
- There is no frequency drift with temperature variation DRAs
- DRAs can be fabricated in various shapes such as cylindrical, hemispherical rectangular, cylindrical Ring and have more design flexibility.



FUNDAMENTALS OF DRA

❑ **Performance Features of DRA:**

- **It is a low loss antenna due to low dissipation factor (tan δ) of dielectric materials.**
- **high gain & high efficiency due to absence of conductors and surface wave losses.**
- **a Volumetric Source and good Radiation Power Factor (real power/reactive power).**
- **It can be excited by various feeds such as probes, slot, microstrip lines, dielectric image guides, coplanar lines and waveguide slot**

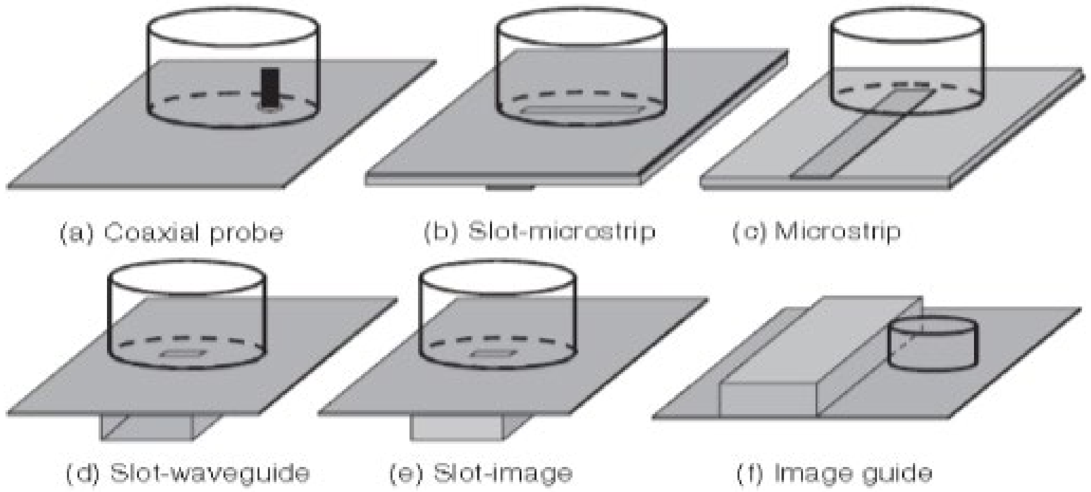


Fig. 2 Different excitation methods of DRA

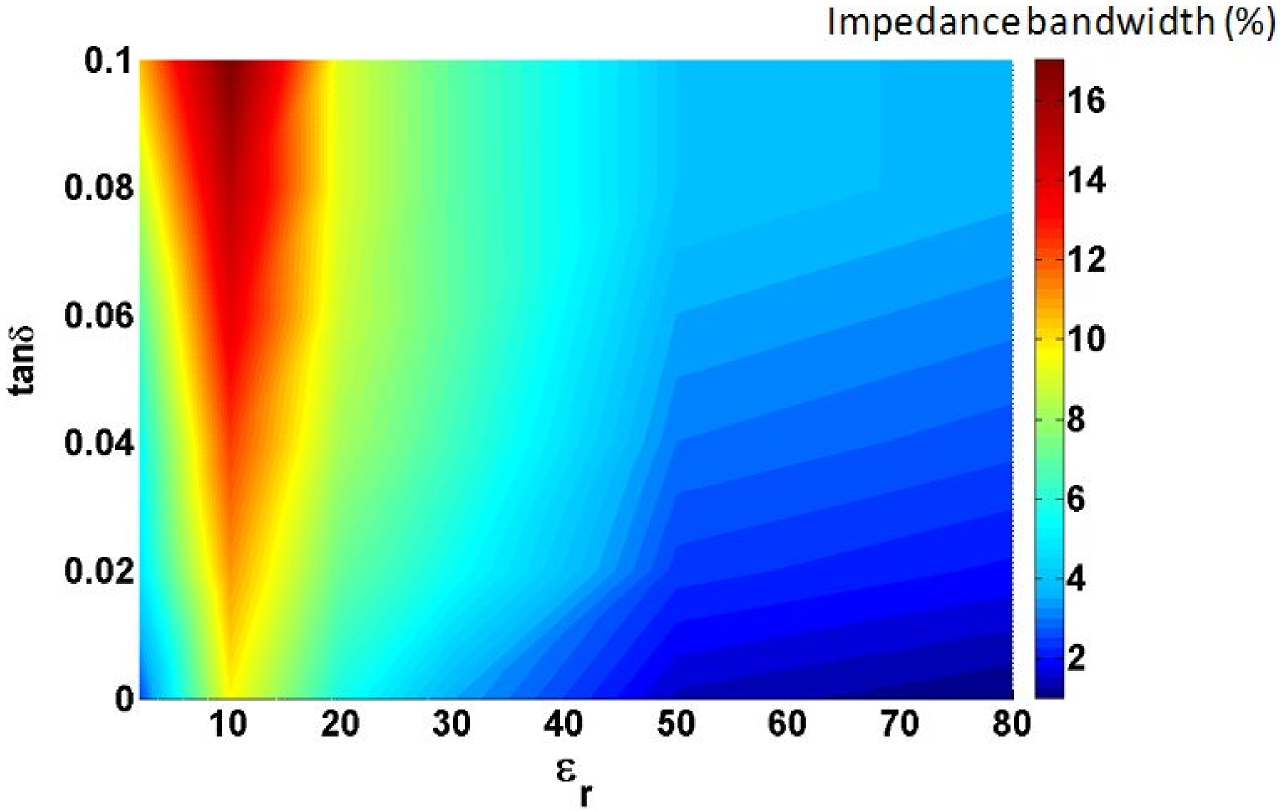
Bandwidth Enhancement Techniques of Dielectric Resonator Antenna. Available from: https://www.researchgate.net/publication/265036843_Bandwidth_Enhancement_Techniques_of_Dielectric_Resonator_Antenna [accessed Apr 25 2021].

FUNDAMENTALS OF DRA

❑ Design Challenges in DRA:

- ↑ (ε_r) ⇒ ↓ the DR size,

but, continuous ↑↑ (ε_r) ⇒ also ↑↑ Q-factor ⇒ narrow bandwidth + temperature sensitive resonances.



Impedance bandwidth according to the dielectric permittivity and loss tangent

FUNDAMENTALS OF DRA

❑ Design Challenges in DRA:

- ↑ (ε_r) ⇒ ↓ the DR size,

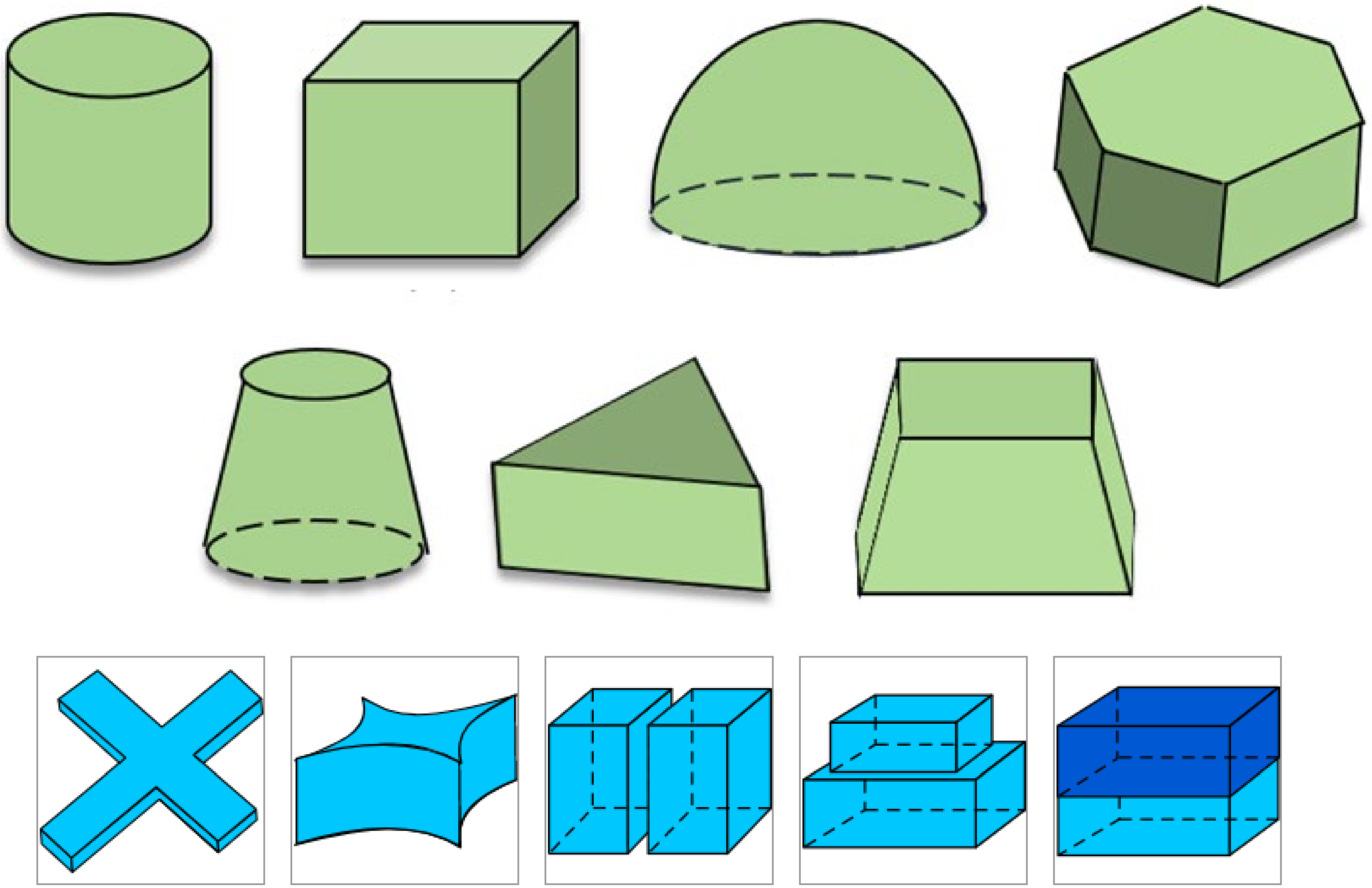
  but, continuous ↑↑ (ε_r) ⇒ also ↑↑ Q-factor ⇒ narrow bandwidth + temperature sensitive resonances.
- For GSM/PCS antenna;

  to achieve requisite bandwidth (εr) < 30

  to operate below 3 GHz with (εr) < 30 ⇒ Antenna size becomes large.
- Using ground plane(Image theory) ⇒ Reduces the antenna size by two but sometimes, Ground plane increases the volume of the whole antenna.
- Research on DRA based handheld antennas is not up to the mark.
- Ensuring circular polarization with simple approach
- Ensuring high gain (more than average 5 dBi) with simple technique is still missing.
- Fabrication/tailoring is a big challenge for some designs
- Development of DRAs on silicon based IC surface in the form of MICs [1]

FUNDAMENTALS OF DRA

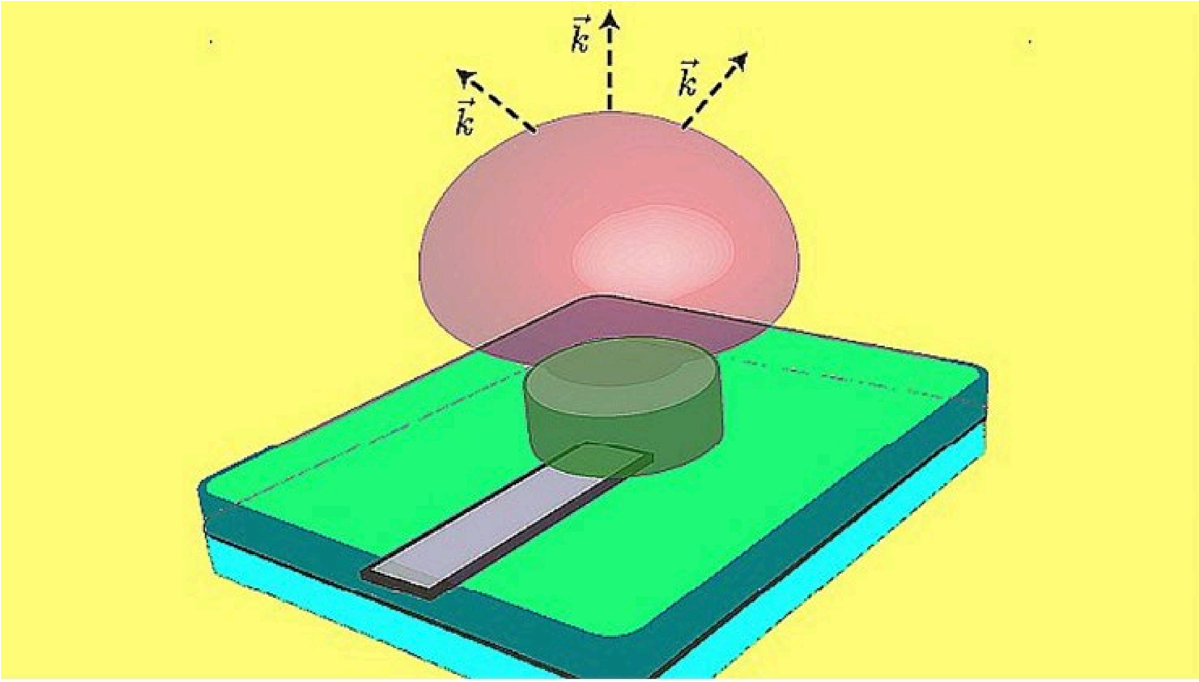
- **Different DRA Shapes:**



FUNDAMENTALS OF DRA

❑ How does DRA work:

1. EM energy coupled to DR
2. DR resonates at one or more its resonant modes
3. Energy escapes from DR and radiates into space

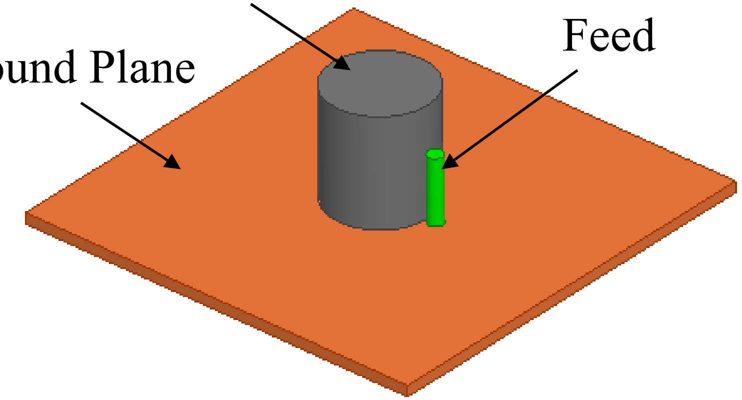


FUNDAMENTALS OF DRA

❑ Different Parts of DRA:

Ground Plane:

- a conducting plane above which the DRA is mounted on.
- may be a three-dimensional copper/brass/steel plate or a conductive coated dielectric sheet.
- Conductive coated sheets are used for medium band/multi band operation, where conductive plates are useful for wideband and ultra wide band operation.



Dielectric Resonator:

- mainly used for resonating as well as radiating purpose.
- placed upon the ground plane. Depending on the aspect ratio and Q factor the resonant frequency, bandwidth, and radiation characteristics varies.

Feed:

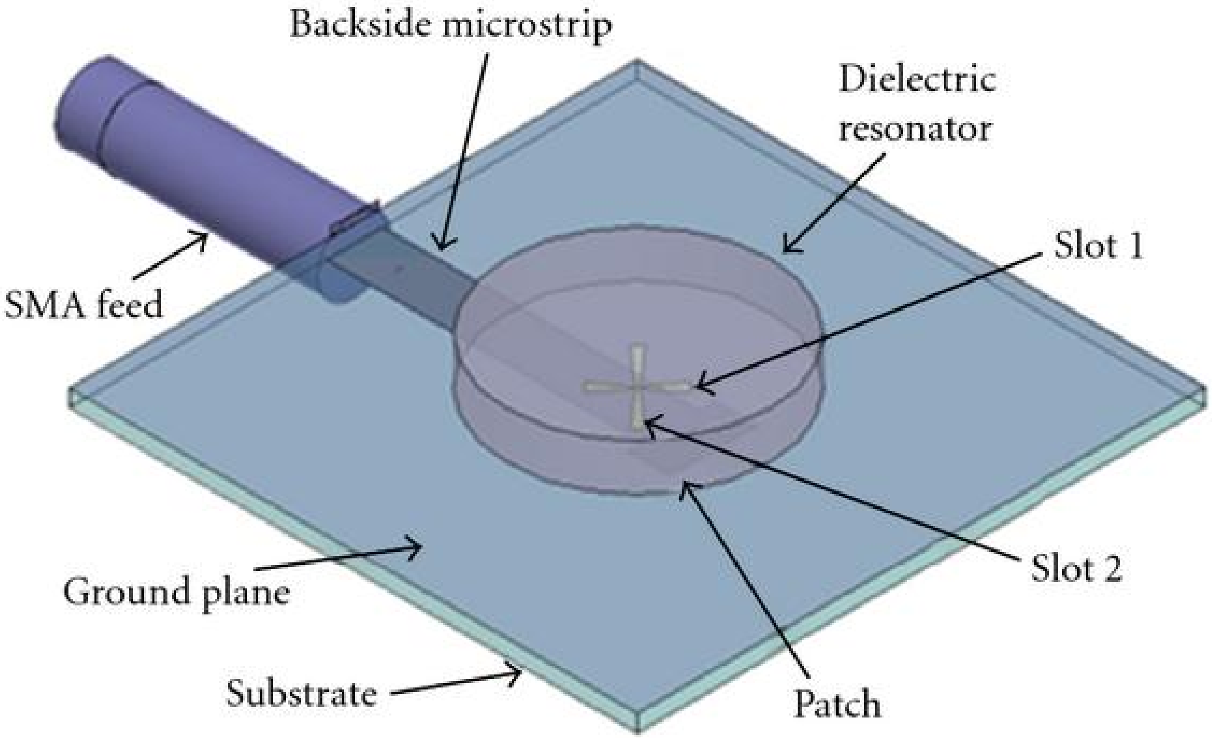
- The type of port used and the location of the port with respect to the DRA shape determine mode excited and power coupled between the port and the antenna.
- The mode or modes excited, the strength of coupling, and the impedance characteristics are important performance figures of the DRA.

FUNDAMENTALS OF DRA

❑ Different Feeding Techniques:

1) Aperture Coupling:

- The common technique to excite DRA either through an aperture or a slot made on the ground plane where the DRA is mounted on.



FUNDAMENTALS OF DRA

❑ Different Feeding Techniques:

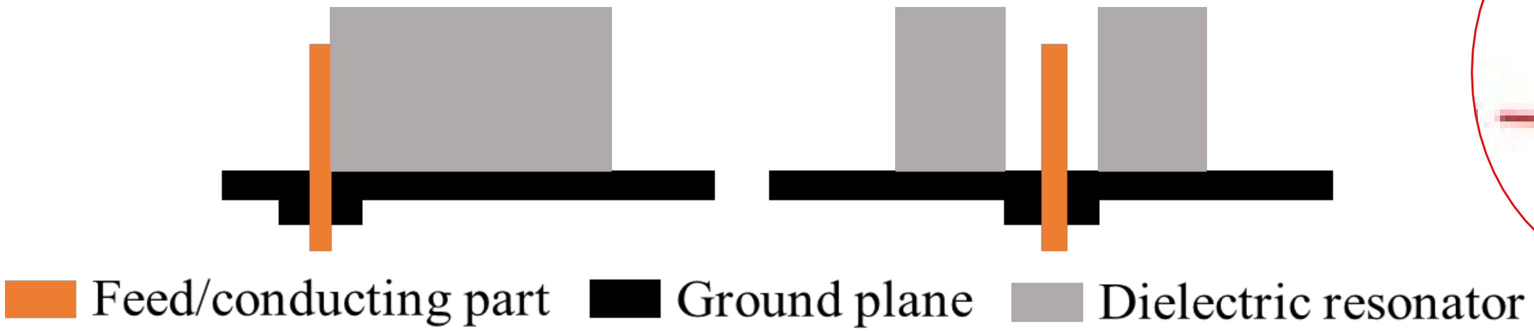
1) Aperture Coupling:

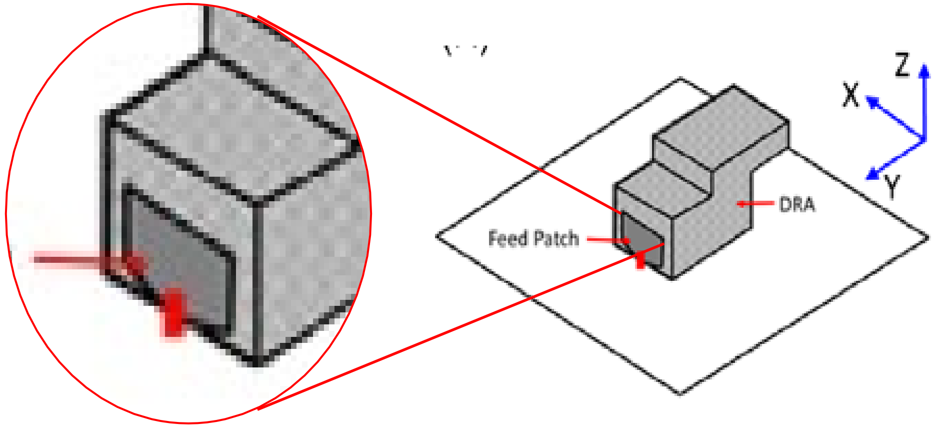
- Small rectangular slot and annular slot as shown above are seem to be most commonly used apertures.
- Cross-shaped slot and C-shaped slots as shown above are mainly dedicated for ensuring circular polarization.
- This approach uses microstrip line feed and avoids unwanted coupling and radiation direct from the feed line.

FUNDAMENTALS OF DRA

❑ Different Feeding Techniques:

2) Probe Coupling:



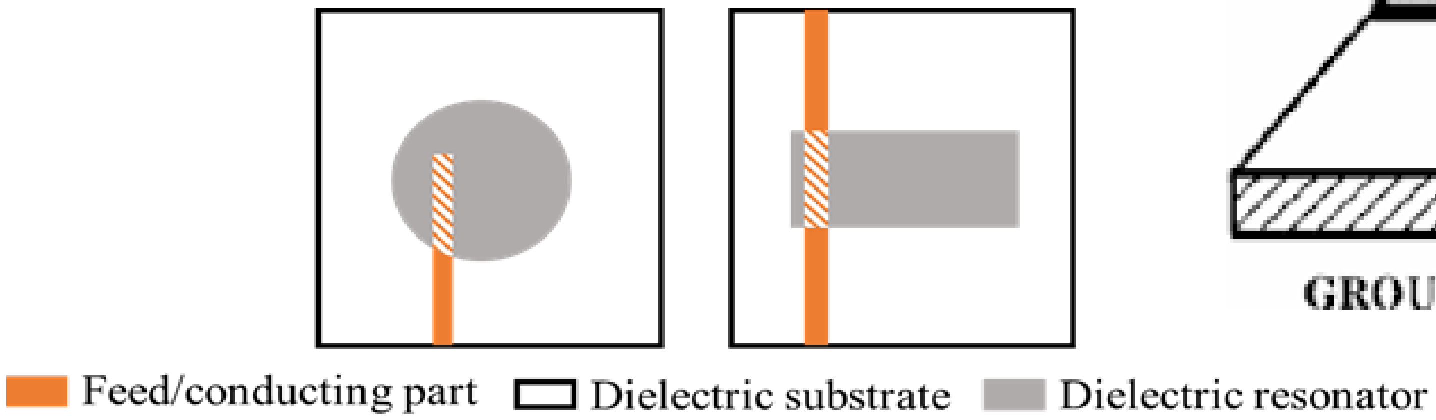


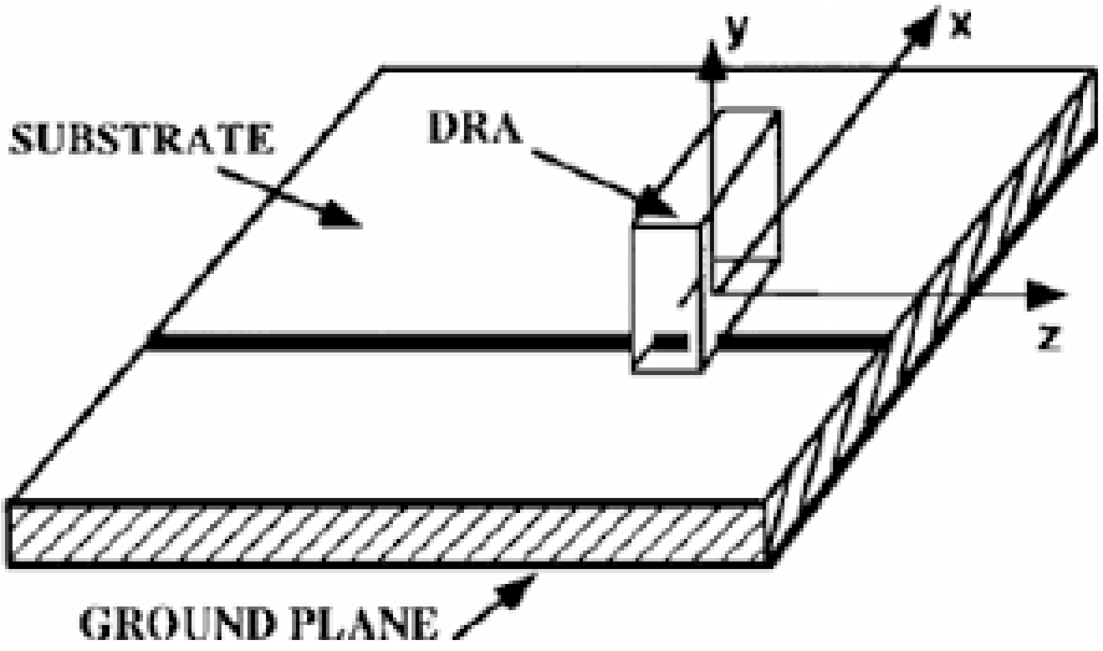
- As shown above the probe is a coaxial transmission line extends from the bottom of the ground plane
- The probe can be placed at the centre of the DRA (either embedding/non embedding the DRA surface) or adjacent to the DRA wall.
- Sometimes this is directly coupled to the DRA wall and sometimes via small metal strip.
- In case of only probe the height and in case of metal strip the dimension of the strips controls the resonance frequency as well as resonance deep by means of achieving strong coupling.
- It can be noted that, the position of the probe decides the mode of operation/excitation.

FUNDAMENTALS OF DRA

❑ Different Feeding Techniques:

3) Microstrip Line Coupling:



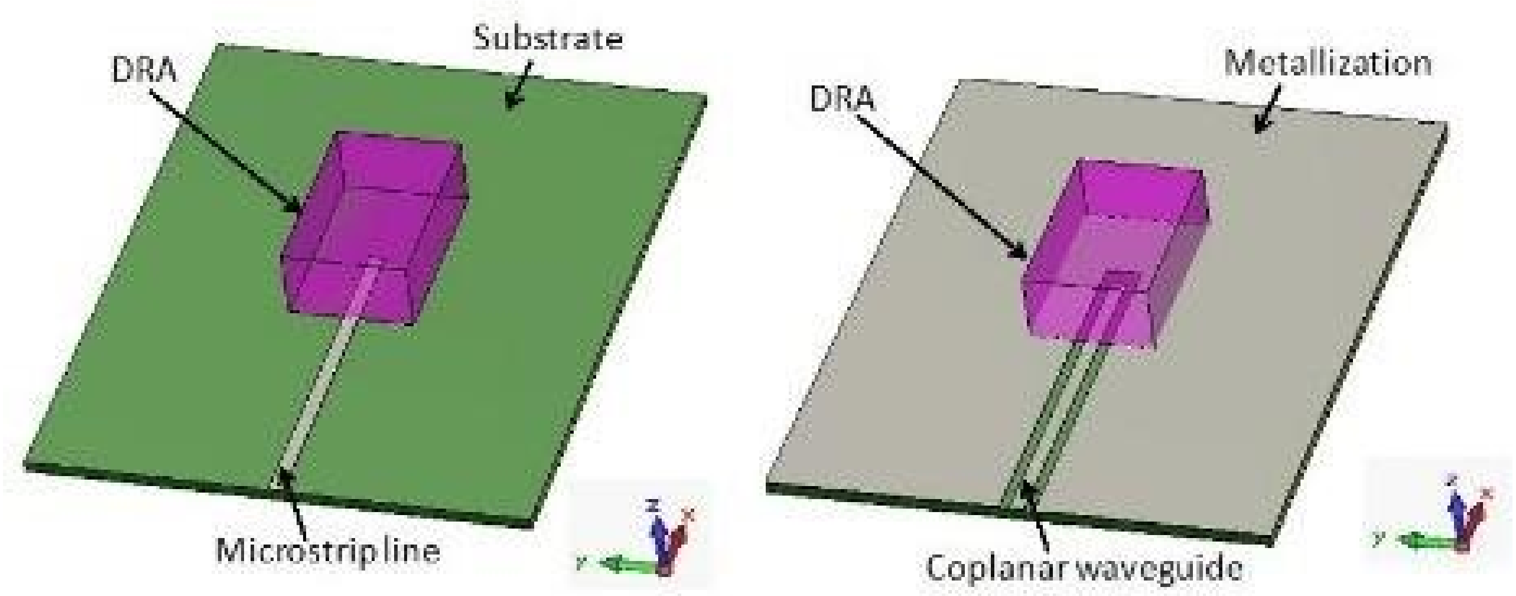


- This type of coupling are quite useful in context to DRAs used in microwave circuits.
- This coupling can be helpful in exploring $HE_{11\delta}$ mode in cylindrical shaped DRA and $TE_{x\delta 11}$ mode in rectangular shaped DRA.

FUNDAMENTALS OF DRA

❑ Different Feeding Techniques:

4) Coplanar Coupling:

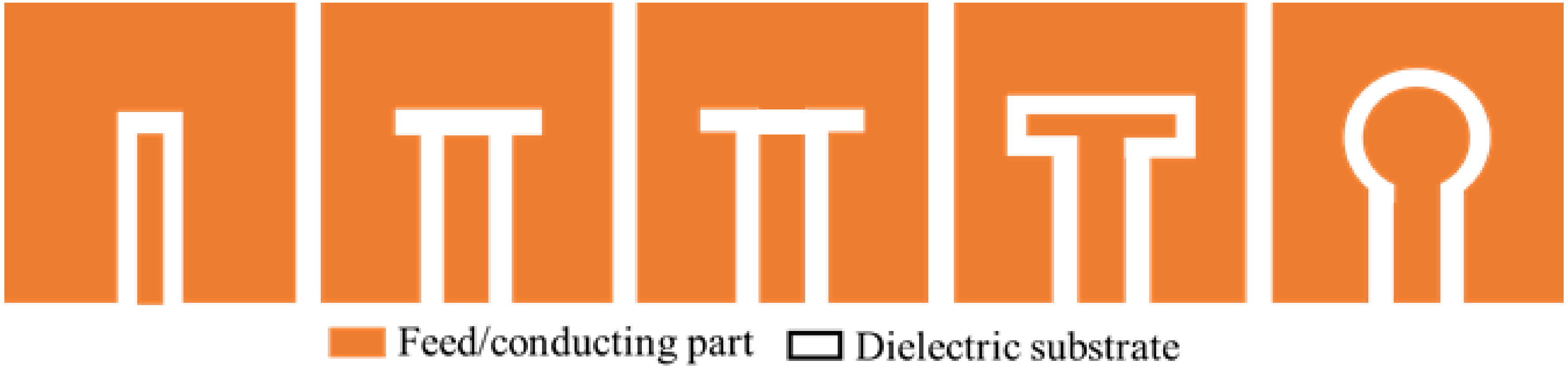


- As of open-circuit microstrip line, open-circuit coplanar waveguides can also be used for coupling to dielectric resonator antennas as shown above.

FUNDAMENTALS OF DRA

❑ Different Feeding Techniques:

4) Coplanar Coupling:



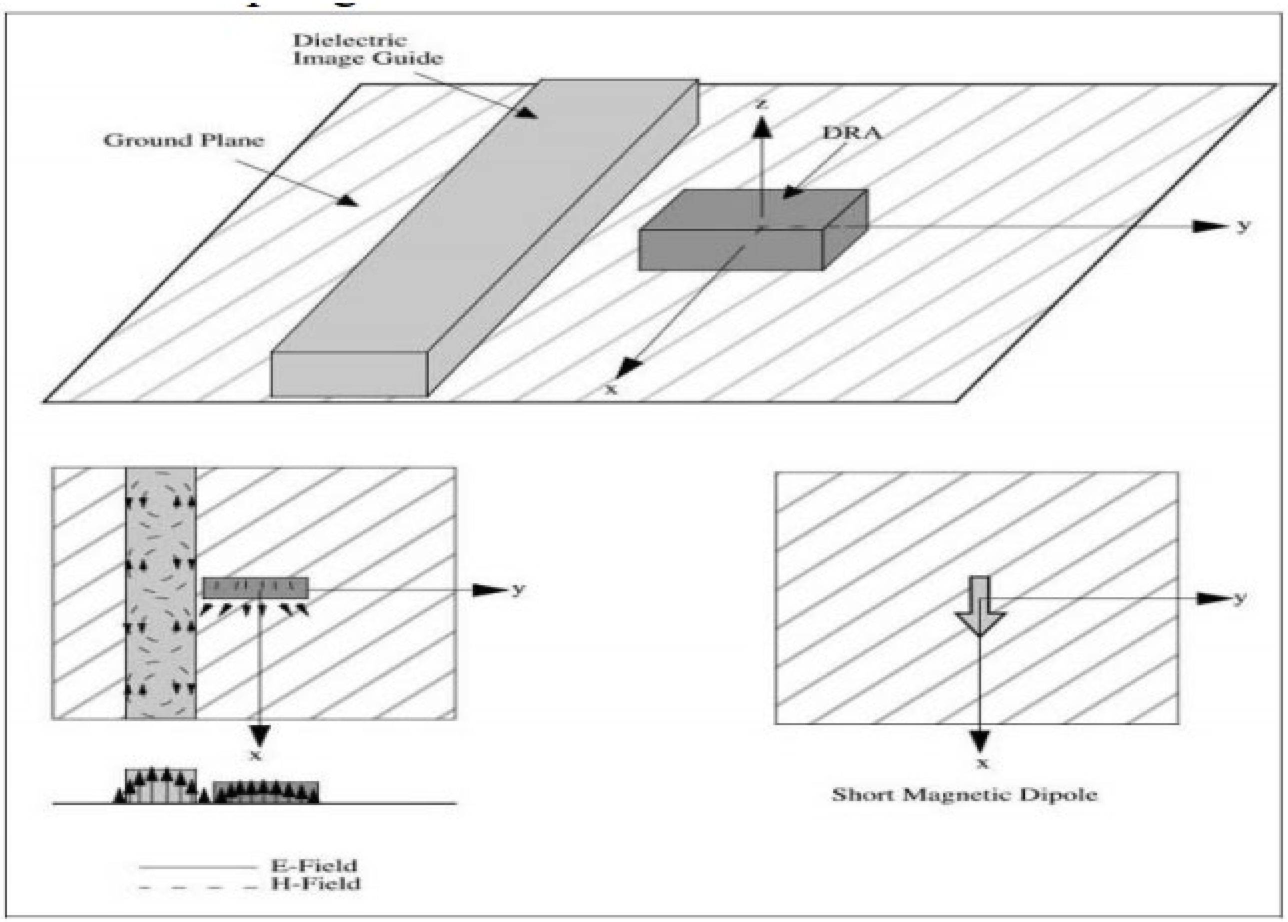
- Sometimes additional stubs and loop are also incorporated for controlling impedance matching.
- It can be noted that, among others the coplanar loop offers non-obtrusive coupling (does not significantly perturb the fields inside the DRA).

FUNDAMENTALS OF DRA

❑ Different Feeding Techniques:

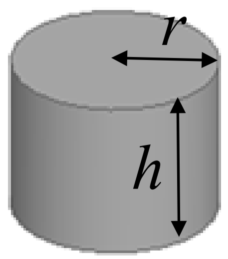
5) Dielectric Image Guide Coupling:

- high permittivity
- rectangular shape
- adjustable dimensions
- low-loss material
- non-intrusive
- wide bandwidth.



- Dielectric image guide coupling seems to be more efficient than microstrip at millimetre-wave frequency ranges due to conductor loss.
- It mainly minimizes the large conductor losses and offers improved couplings by operating the guide closer to the cut-off frequency as shown above.
- This method can be best utilized as a series feed to a linear array of DRAs.

Typical Mode Excitation



❑ Cylindrical DRA:

ModeTE01:

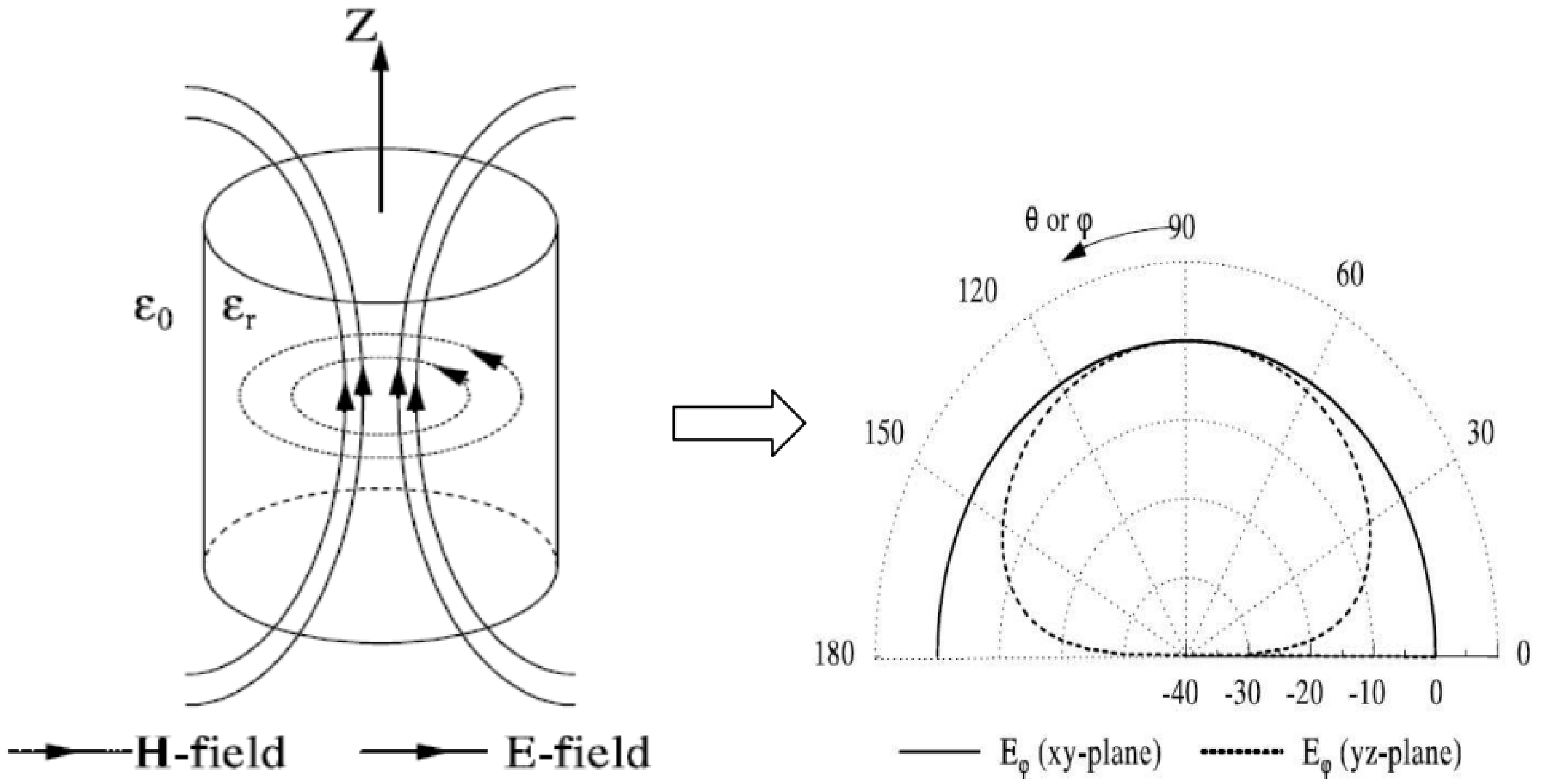
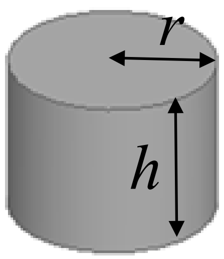


Fig2.8: ModeTE01 and its broadside far field radiation pattern [1].

Typical Mode Excitation



❑ Cylindrical DRA:

Mode TM01:

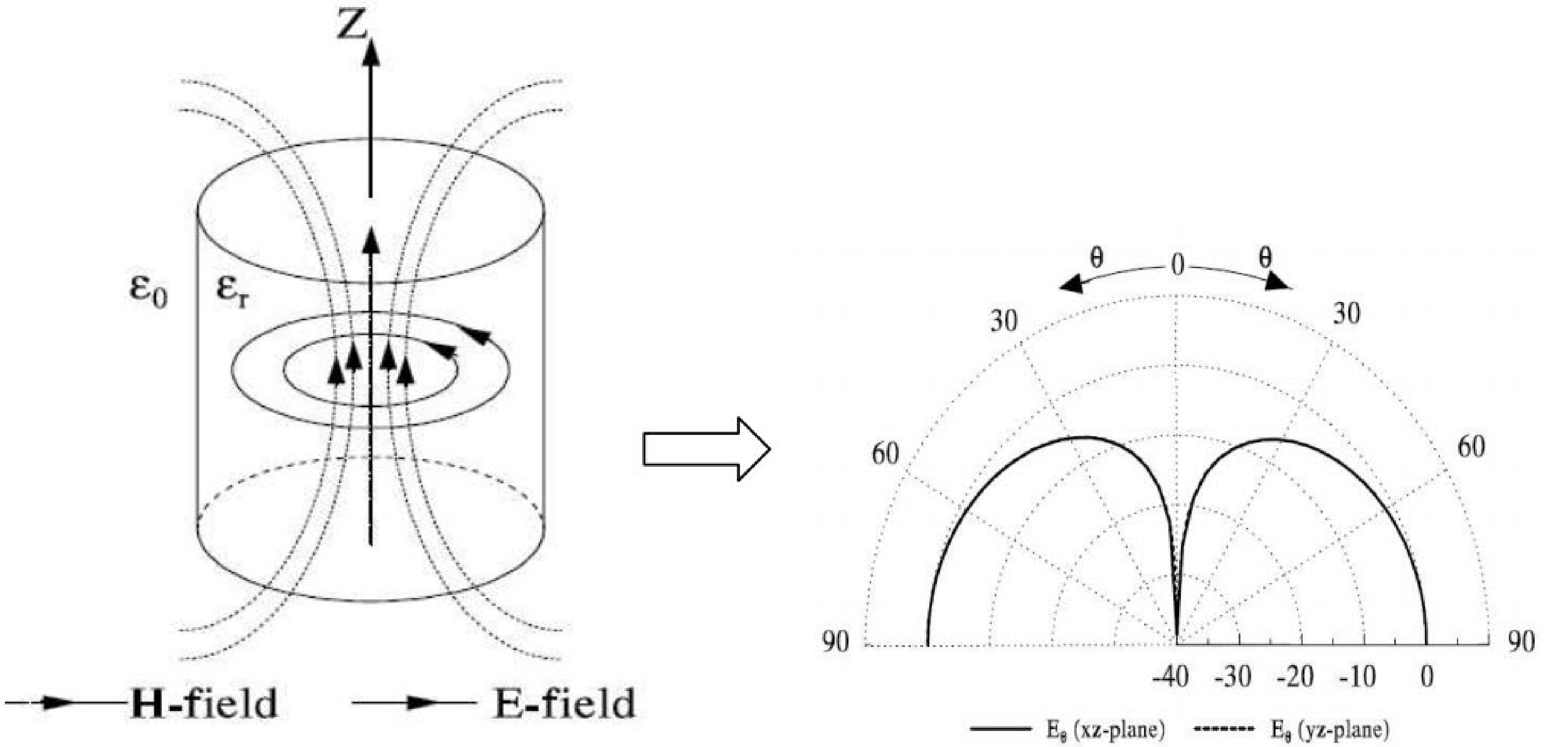
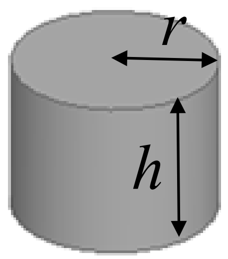


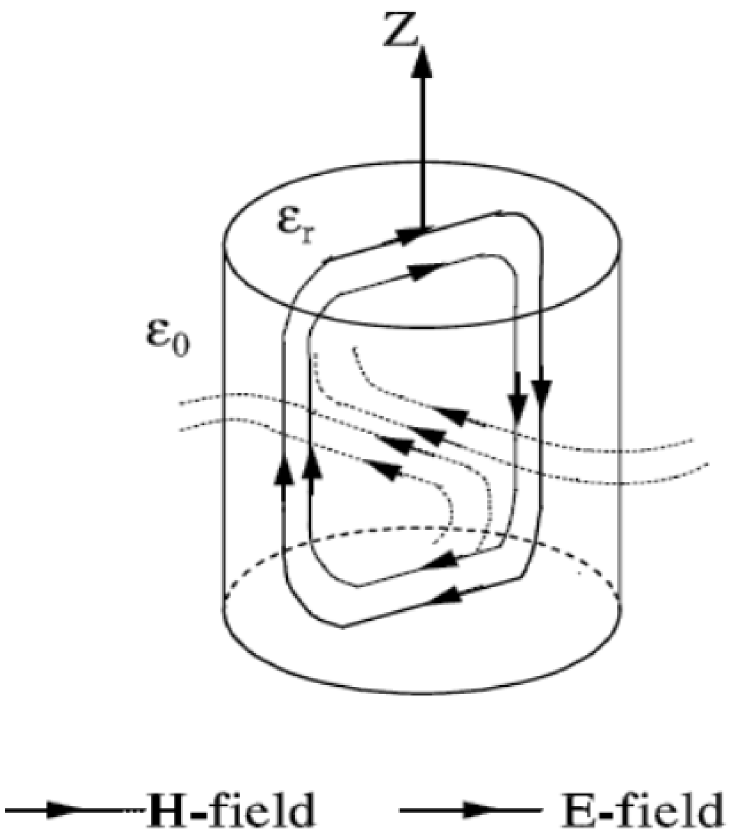
Fig2.9: ModeTM01 and its monopole like far field radiation pattern [1].

Typical Mode Excitation



- **Cylindrical DRA:**

Mode TM_{110} (HEM_{11}):



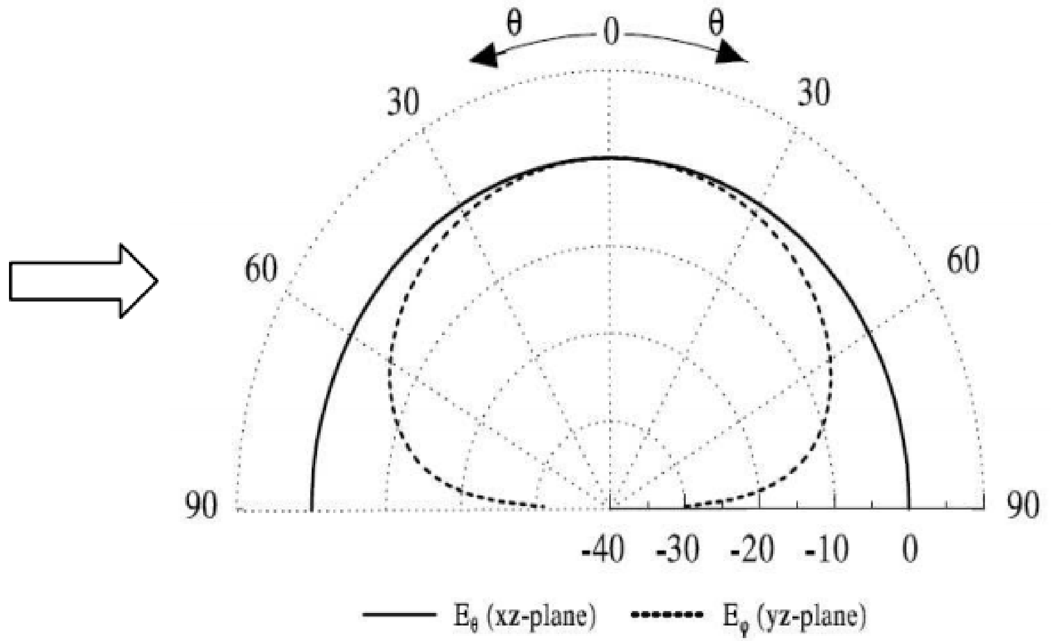
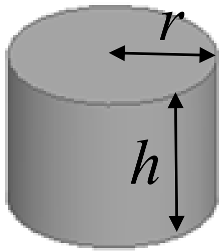


Fig2.10: Mode TM_{110} (HEM_{11}) and its broadside far field radiation pattern [1].

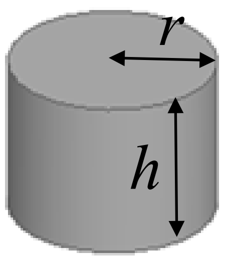
Typical Mode Excitation



❑ Cylindrical DRA:

- excitation source may resonate several modes simultaneously
- The field strength for a typical mode depends upon the exactness of the **feed location** and **its operating frequency**.
- The far field radiation patterns have clear resemblance to other renowned antenna types
  - TE_{01} seems like radiation pattern of **half wavelength narrow slot on the ground plane and directed to the axis of resonator**
  - TM_{01} seems like **a quarter wavelength monopole above the ground plane**
  - HEM_{11} resembles to that of **half wavelength narrow slot on the ground plane**

Typical Mode Excitation



❑ Cylindrical DRA:

- gradual transformation in pattern shape takes place with the **changing locations** by an aperture slot under the DRA.

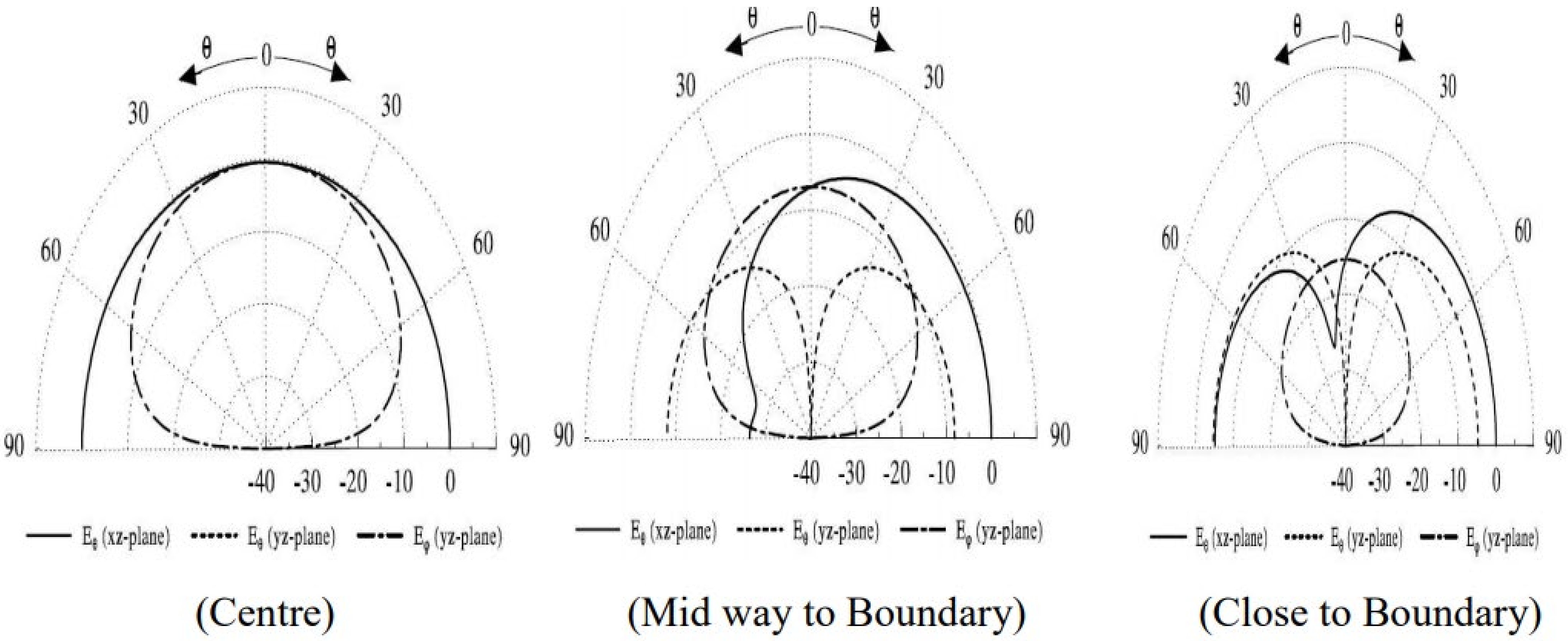


Fig2.11: Changing radiation patterns corresponding to different slot positions under DRA [1]

Circular Polarized DRA

- ❑ **Single Feed DRA:**

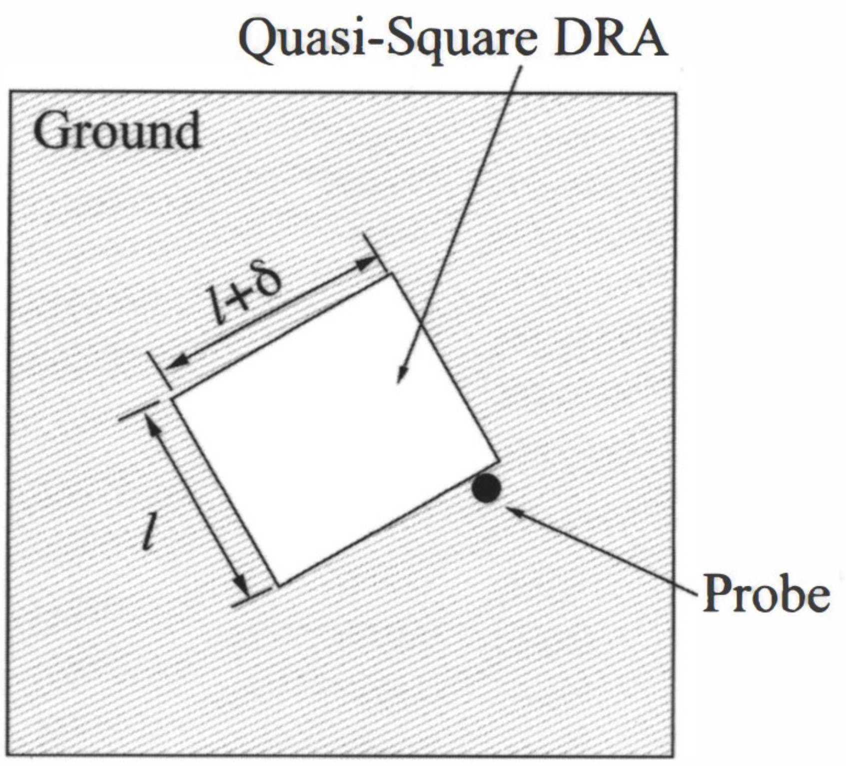


Figure 6a. An example of a single-point-fed circular-polarized dielectric resonator antenna: $BW_{cp} = 6.6\%$ (BW_{cp} **is the** -3 **dB axial-ratio bandwidth) (from [159]).**

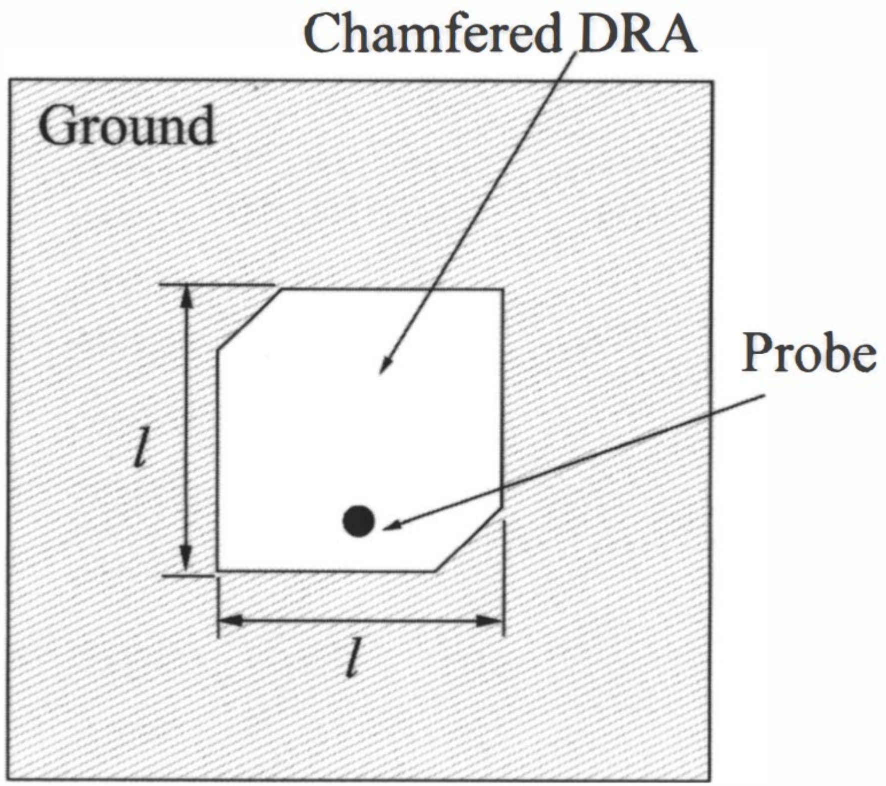


Figure 6b. An example of a single-point-fed circular-polarized dielectric resonator antenna: $BW_{cp} = 4\%$ **(from [7]).**

exciting two sets of degenerate orthogonal modes (same resonant frequency and orthogonal field distribution)
Phase difference is introduced by perturbation of geometry to break the symmetry of the two degenerate modes

[1] A. Petosa and A. Ittipiboon, "Dielectric Resonator Antennas: A Historical Review and the Current State of the Art," in *IEEE Antennas and Propagation Magazine*, vol. 52, no. 5, pp. 91-116, Oct. 2010, doi: 10.1109/MAP.2010.5687510.

Circular Polarized DRA

- **Single Feed DRA:**

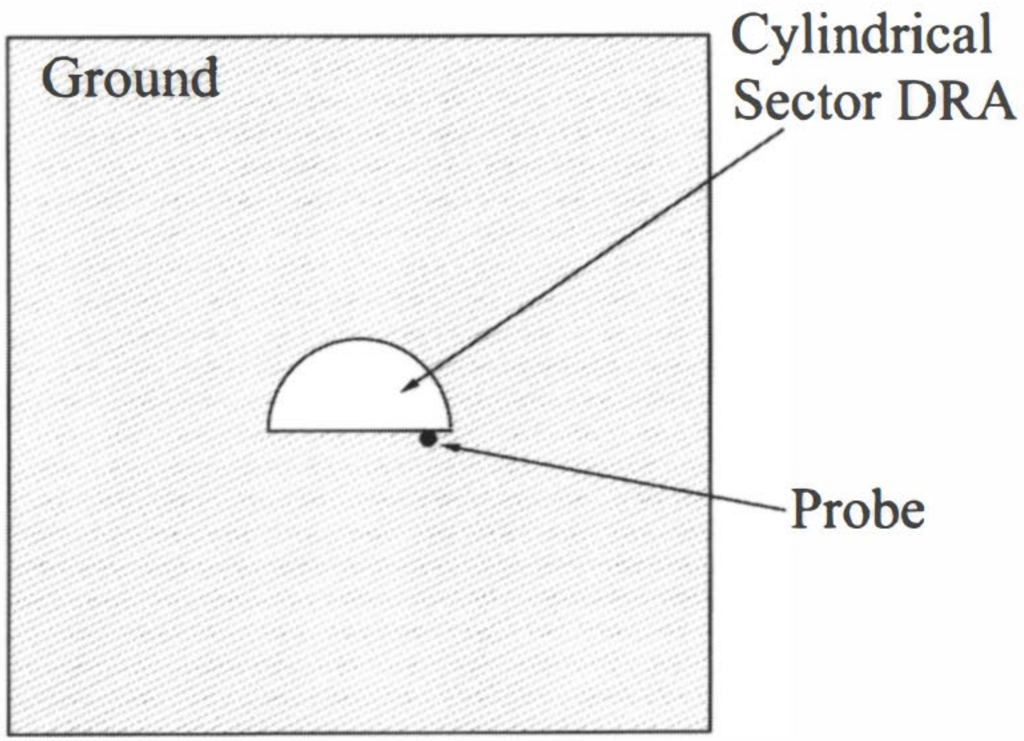


Figure 6c. An example of a single-point-fed circular-polarized dielectric resonator antenna: $BW_{cp} = 10\%$ (from [160]).

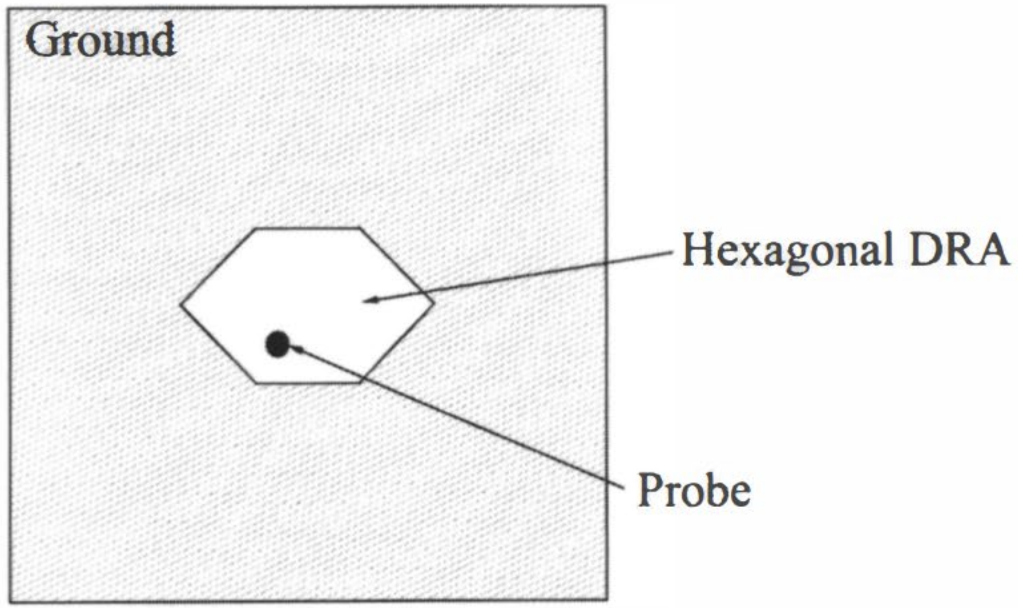


Figure 6d. An example of a single-point-fed circular-polarized dielectric resonator antenna: $BW_{cp} = 14.8\%$ (from [161]).

exciting two sets of degenerate orthogonal modes

[1] A. Petosa and A. Ittipiboon, "Dielectric Resonator Antennas: A Historical Review and the Current State of the Art," in *IEEE Antennas and Propagation Magazine*, vol. 52, no. 5, pp. 91-116, Oct. 2010, doi: 10.1109/MAP.2010.5687510.

Circular Polarized DRA

- Single Feed DRA:

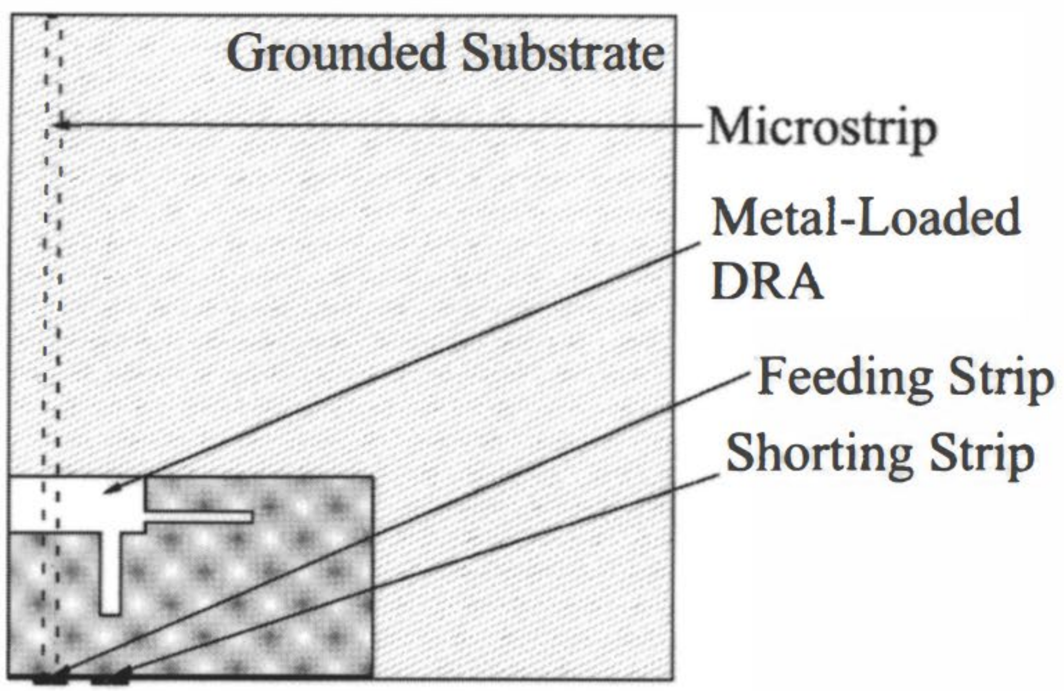


Figure 6e. An example of a single-point-fed circular-polarized dielectric resonator antenna: $BW_{cp} = 7.35\%$ (from [162]).

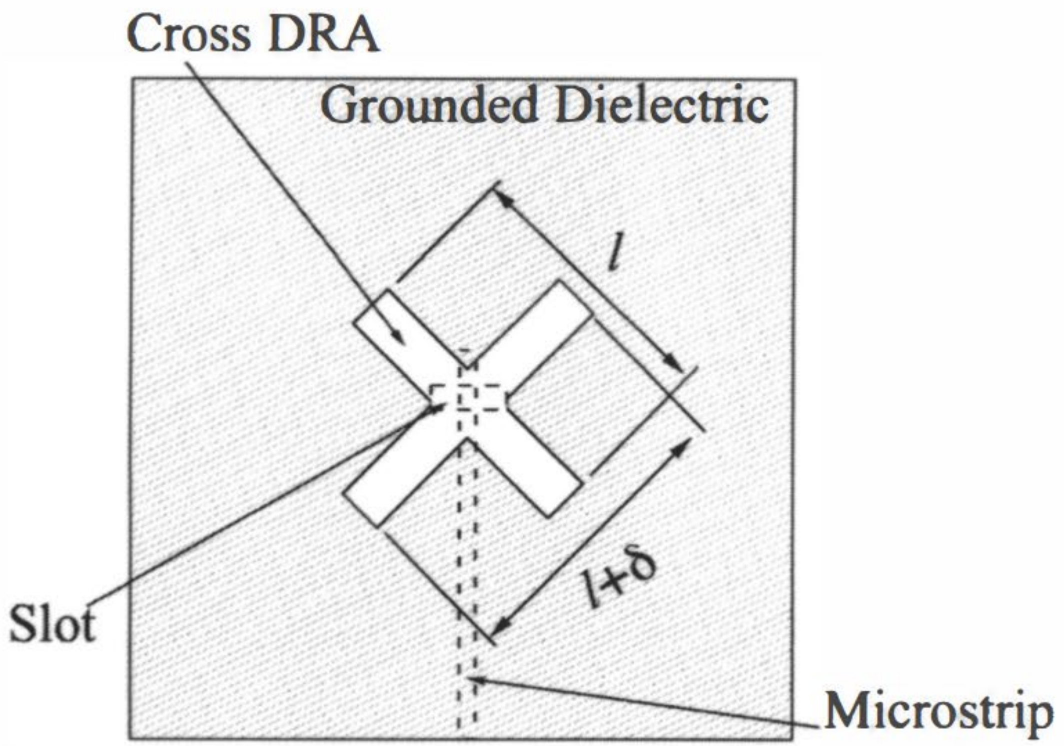


Figure 6f. An example of a single-point-fed circular-polarized dielectric resonator antenna: $BW_{cp} = 4.5\%$ (from [85]).

exciting two sets of degenerate orthogonal modes

[1] A. Petosa and A. Ittipiboon, "Dielectric Resonator Antennas: A Historical Review and the Current State of the Art," in *IEEE Antennas and Propagation Magazine*, vol. 52, no. 5, pp. 91-116, Oct. 2010, doi: 10.1109/MAP.2010.5687510.

Circular Polarized DRA

❑ **Single Feed DRA:**

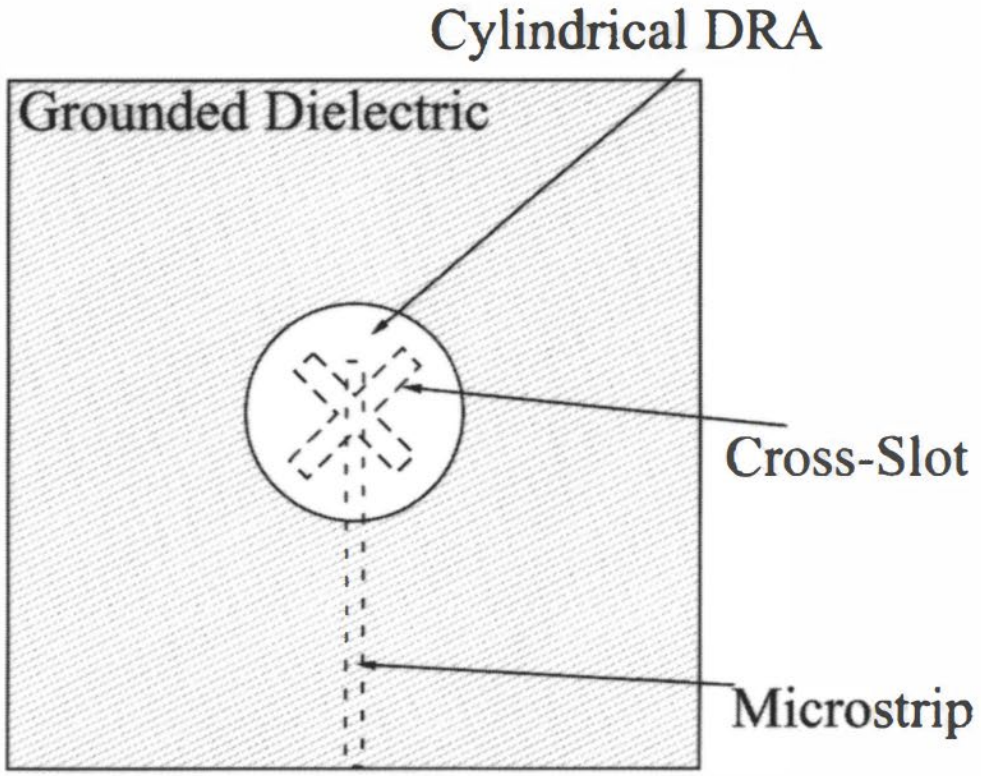


Figure 6g. An example of a single-point-fed circular-polarized dielectric resonator antenna: $BW_{cp} = 3.9\%$ **(from [91]).**

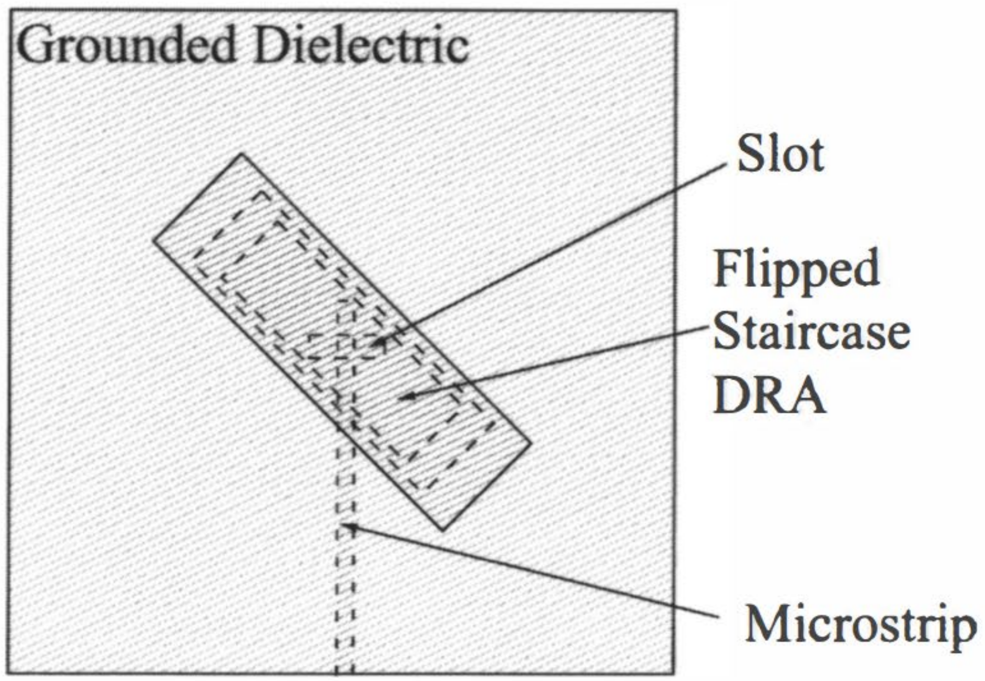


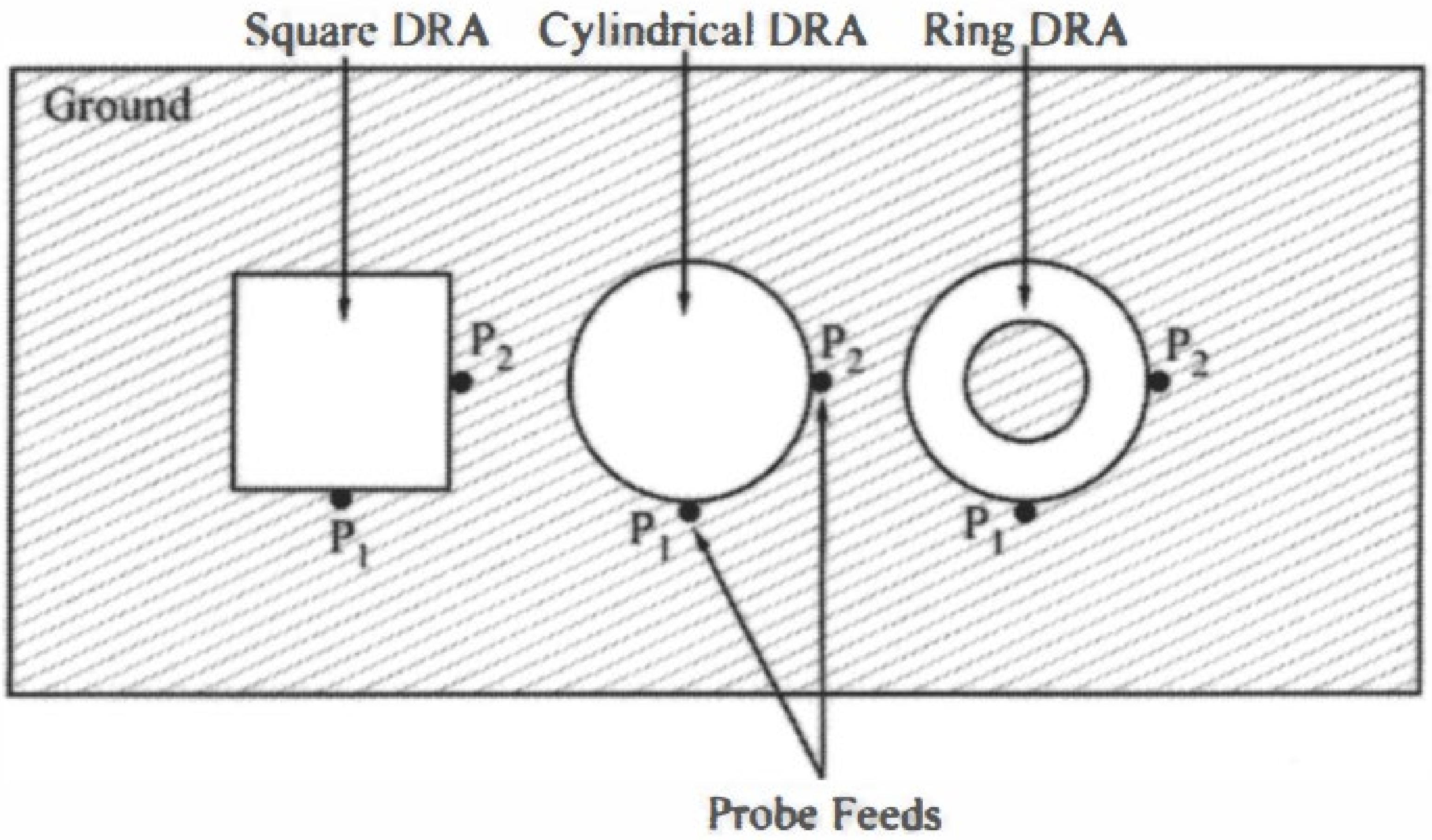
Figure 6h. An example of a single-point-fed circular-polarized dielectric resonator antenna: $BW_{cp} = 10.2\%$ **(from [163]).**

exciting two sets of degenerate orthogonal modes

[1] A. Petosa and A. Ittipiboon, "Dielectric Resonator Antennas: A Historical Review and the Current State of the Art," in *IEEE Antennas and Propagation Magazine*, vol. 52, no. 5, pp. 91-116, Oct. 2010, doi: 10.1109/MAP.2010.5687510.

Circular Polarized DRA

- **Dual Feed DRA:**



excite orthogonal modes with two feeds of 90 degrees phase difference

[1] A. Petosa and A. Ittipiboon, "Dielectric Resonator Antennas: A Historical Review and the Current State of the Art," in *IEEE Antennas and Propagation Magazine*, vol. 52, no. 5, pp. 91-116, Oct. 2010, doi: 10.1109/MAP.2010.5687510.

Circular Polarized DRA

❑DRA Array:

Sequential rotation of DRA improves AR bandwidth

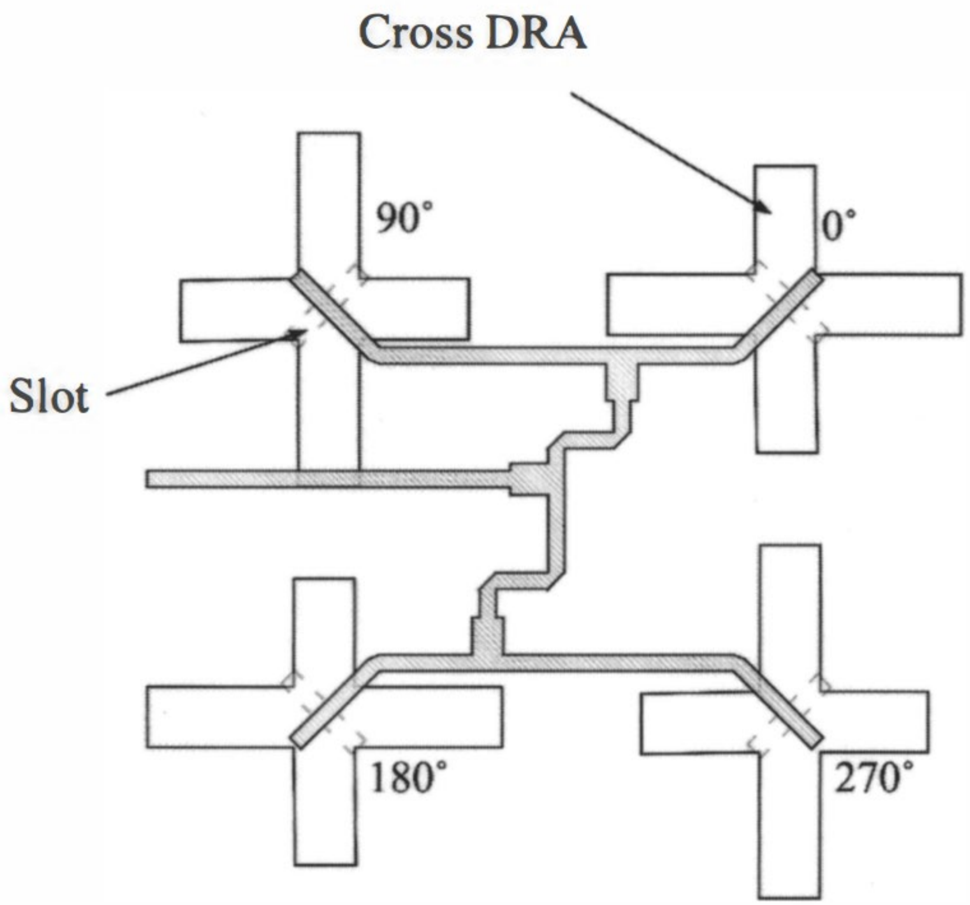


Figure 8a. An example of a dielectric-resonator-antenna array with sequential rotation: $BW_{cp} = 16\%$ (from [56]).

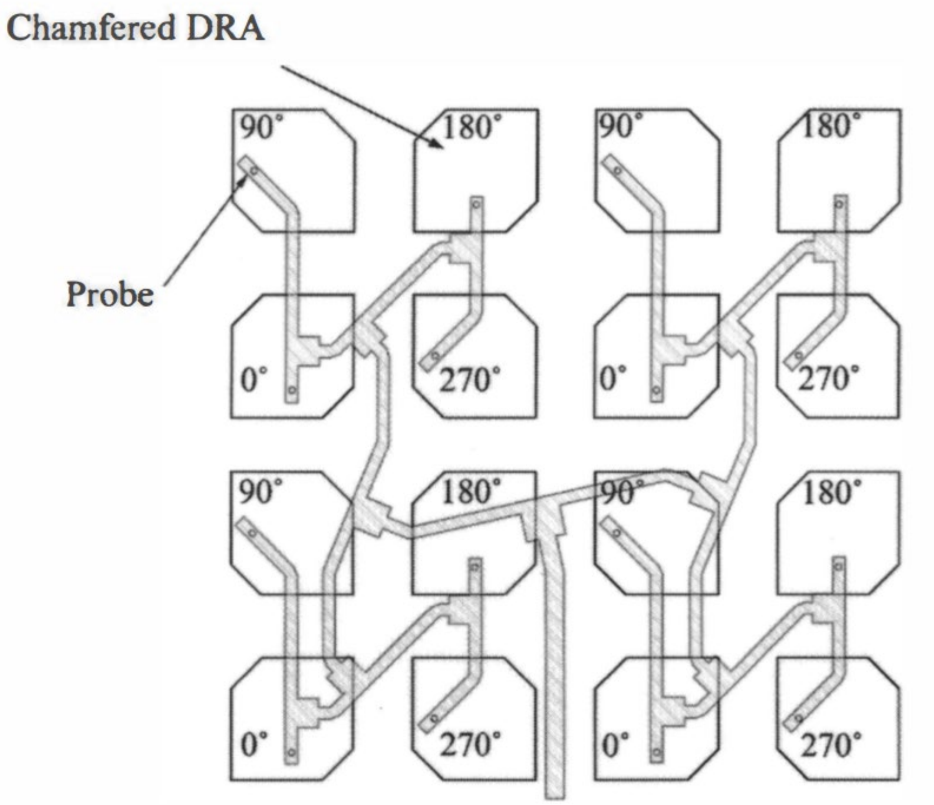
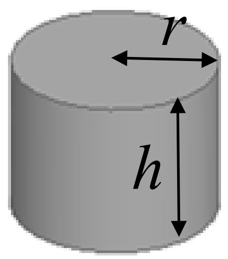


Figure 8b. An example of a dielectric-resonator-antenna array with sequential rotation: $BW_{cp} = 17\%$ (from [7]).

[1] A. Petosa and A. Ittipiboon, "Dielectric Resonator Antennas: A Historical Review and the Current State of the Art," in *IEEE Antennas and Propagation Magazine*, vol. 52, no. 5, pp. 91-116, Oct. 2010, doi: 10.1109/MAP.2010.5687510.

Design Principles of DRA



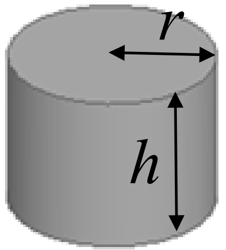
❑ Cylindrical DRA:

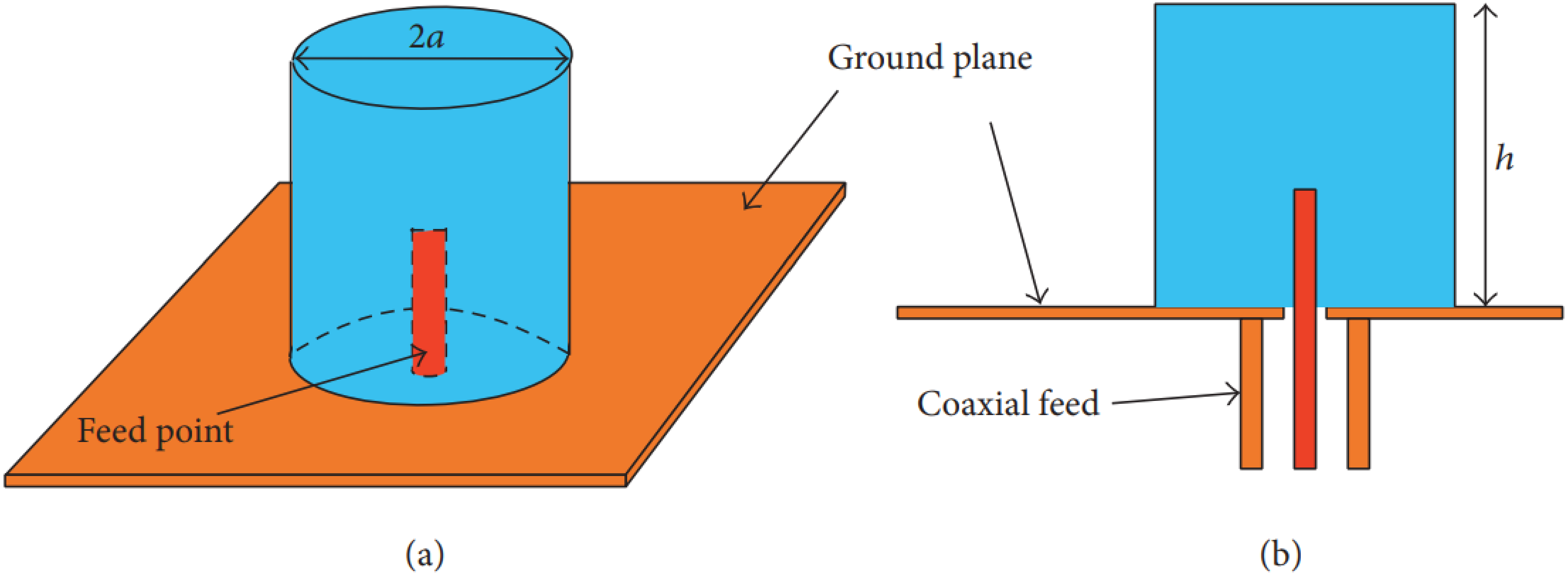
➢ Different modes have different sets of equation for calculating wave number, Resonant Frequency, and Q-factor.

$TE_{01\delta}$ Mode	$TM_{01\delta}$ Mode	$HEM_{11\delta}$ Mode
Wave Number: $k_o a = \frac{2.327}{\sqrt{\varepsilon_r + 1}}\left\{1 + .2123\frac{a}{h} - 0.00898\left(\frac{a}{h}\right)^2\right\}$	Wave Number: $k_o a = \frac{\sqrt{3.83^2 + \left(\frac{\pi a}{2h}\right)^2}}{\sqrt{\varepsilon_r + 2}}$	Wave Number: $k_o a = \frac{6.324}{\sqrt{\varepsilon_r + 2}}\left\{0.27 + 0.36\frac{a}{2h} + 0.02\left(\frac{a}{2h}\right)^2\right\}$
Resonant Frequency: $f_{o(TE01\delta)} = \frac{c\ 2.327}{2\pi a\sqrt{\varepsilon_r + 1}}[1.0 + 0.2123\left(\frac{a}{H}\right) - 0.00898\left(\frac{a}{H}\right)^2]$	Resonant Frequency: $f_{o(TM01\delta)} = \frac{c\sqrt{3.83^2 + \left(\frac{\pi a}{2H}\right)^2}}{2\pi a\sqrt{\varepsilon_r + 2}}$	Resonant Frequency: $f_{o(HEM11)} = \frac{c\ 6.324}{2\pi a\sqrt{\varepsilon_r + 2}}[0.27 + 0.36\left(\frac{a}{2H}\right) + 0.02\left(\frac{a}{2H}\right)^2]$
Q-Factor: $Q = 0.078192\varepsilon^{1.27}\left\{1 + 17.31\left(\frac{h}{a}\right) - 21.57\left(\frac{h}{a}\right)^2 + 10.86\left(\frac{h}{a}\right)^3 - 1.98\left(\frac{h}{a}\right)^4\right\}$	Q-Factor: $Q = 0.008721\varepsilon_r^{0.888413}e^{0.0397475\varepsilon_r}\left\{1 - \left(0.3 - 0.2\frac{a}{h}\right)\left(\frac{38 - \varepsilon_r}{28}\right)\right\} \times \left\{9.498186\frac{a}{h} + 2058..33\left(\frac{a}{h}\right)^{4.322261}e^{-3.50099\left(\frac{a}{h}\right)}\right\}$	Q-Factor: $Q = 0.01007\varepsilon_r^{1.3}\frac{a}{h}\left\{1 + 100e^{-2.05\left(\frac{a}{2h} - \frac{1}{80}\left(\frac{a}{h}\right)^2\right)}\right\}$

DRA Analysis

- ❑ **Cylindrical DRA:**

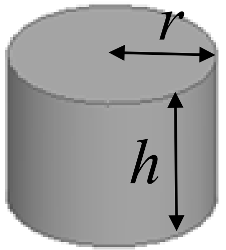


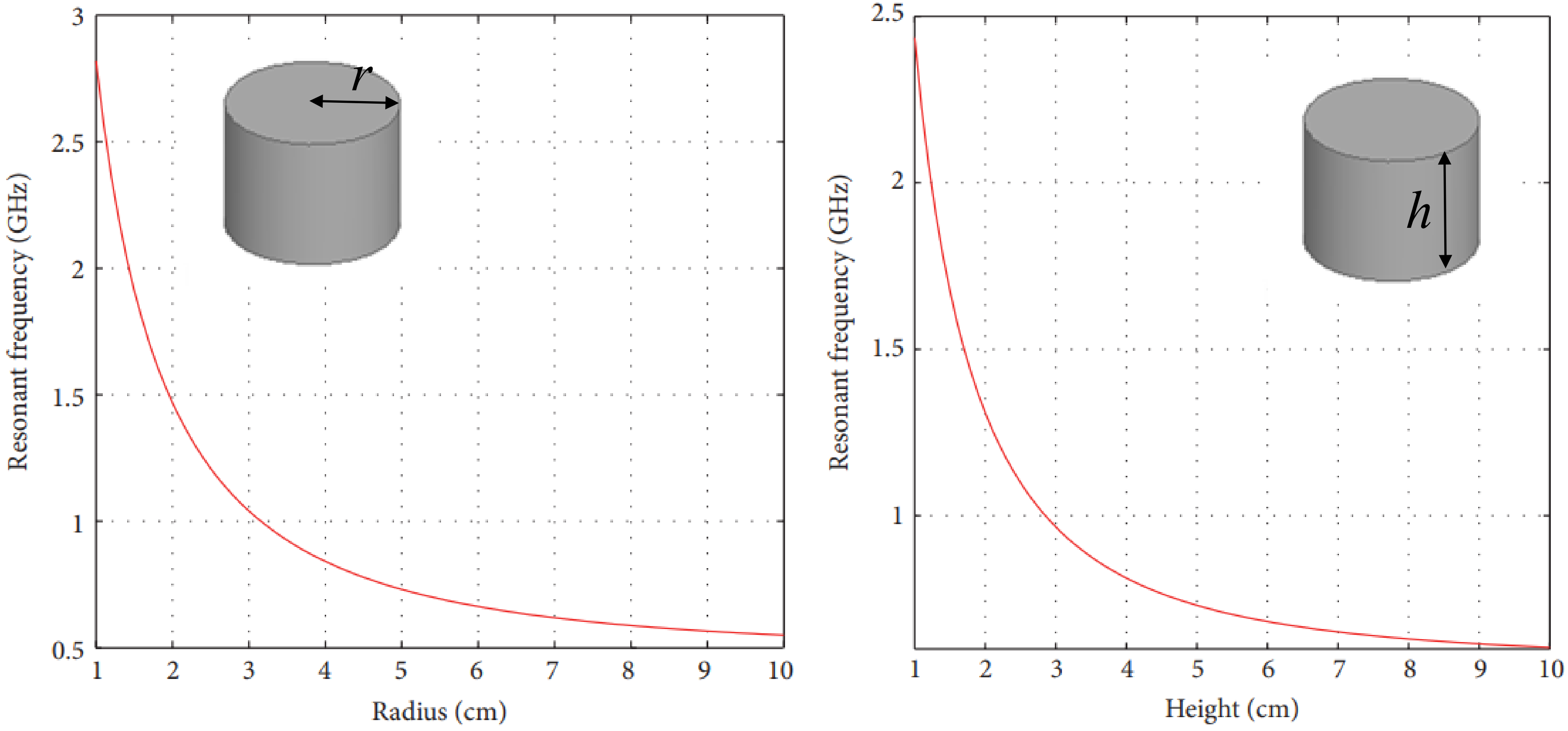


Three-dimensional (a) and cross-sectional view (b) of the probe-fed cylindrical DRA

DRA Analysis

❑ Cylindrical DRA:



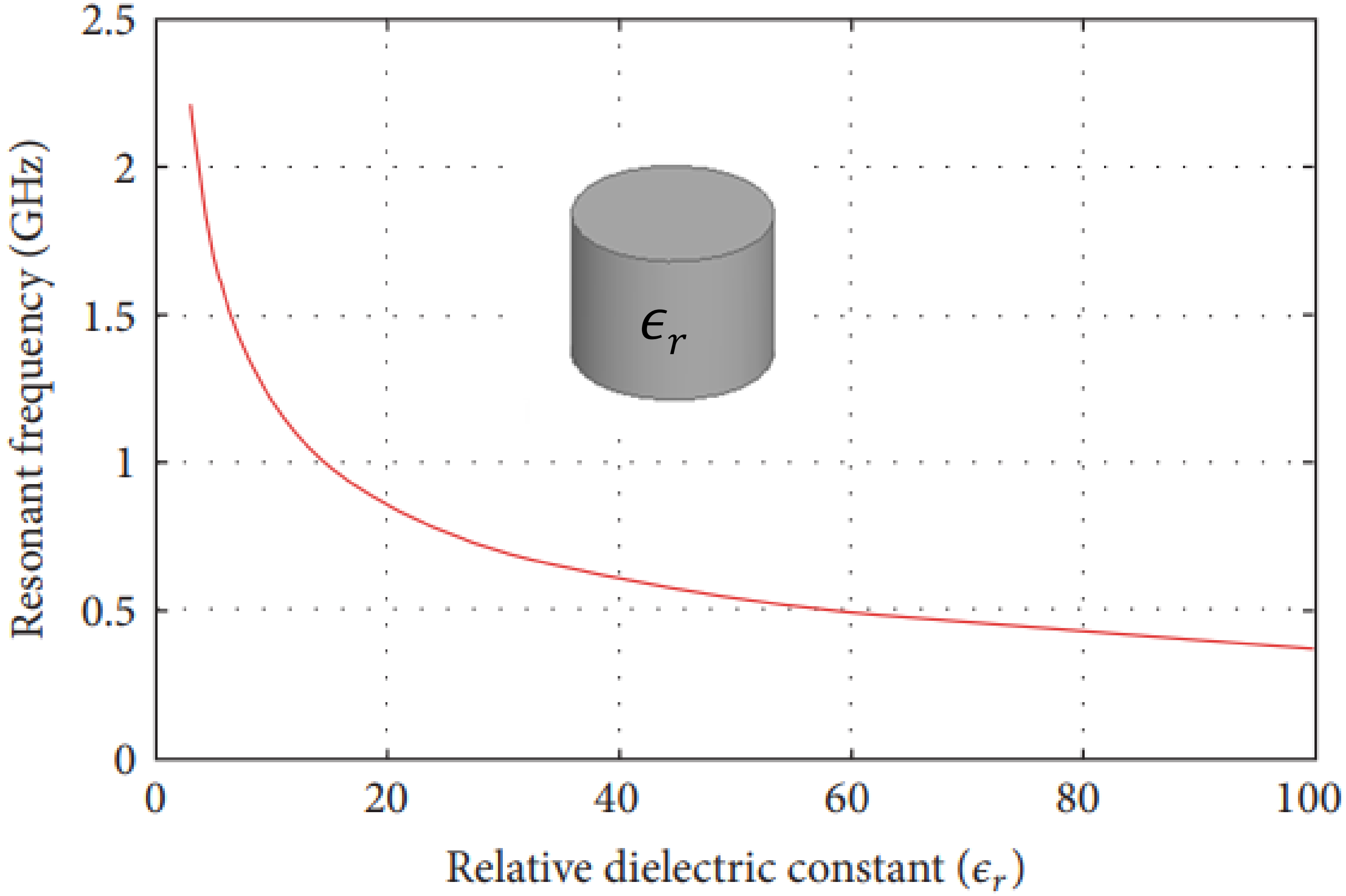


(a) (b)

Resonant frequency as a function of the radius (a) and height (b) of a cylindrical DRA with relative permittivity ϵ_r = 10

DRA Analysis

❑ Cylindrical DRA:

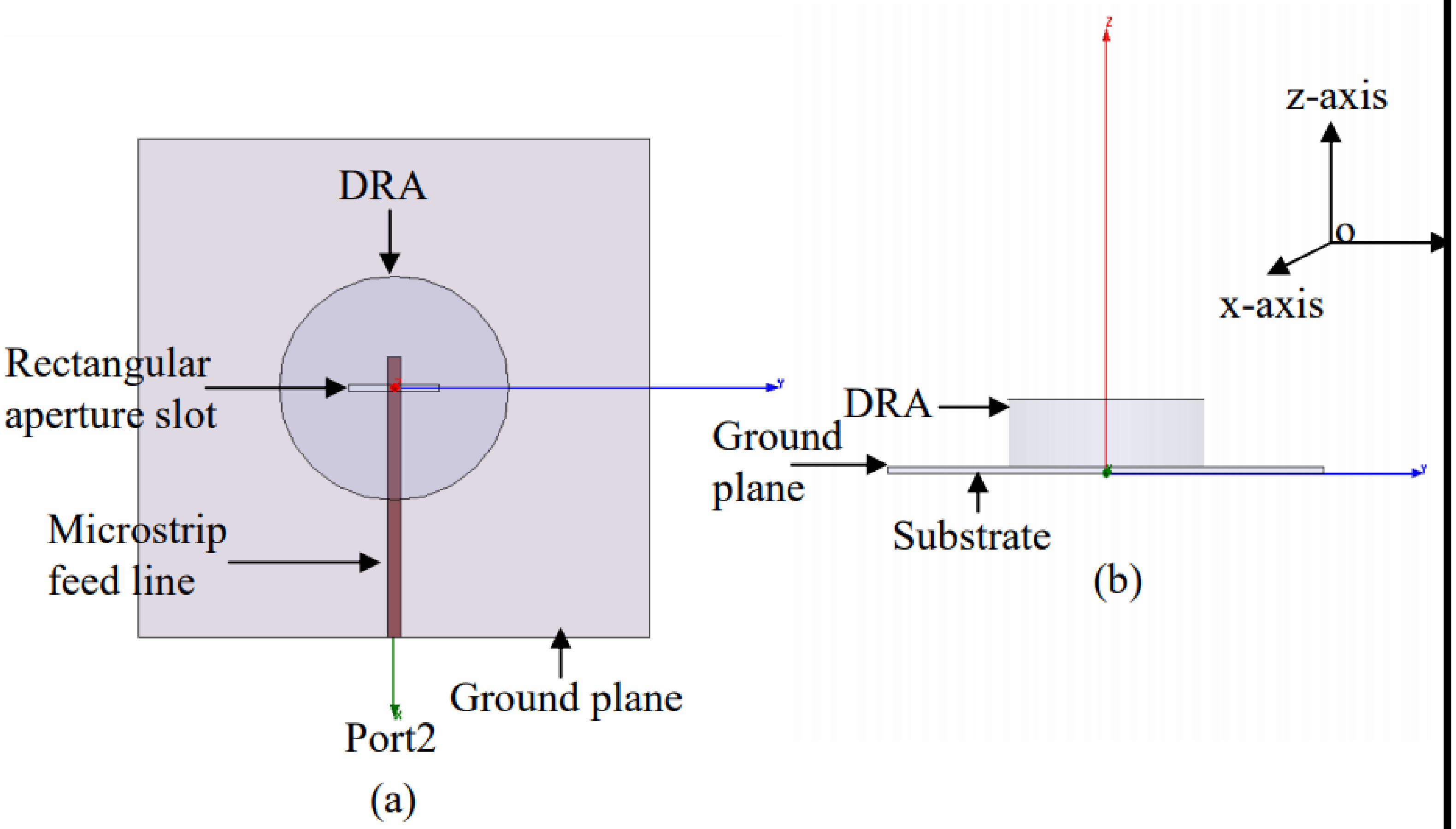


- **most important characteristic**: resonant frequency of the fundamental mode decreases by increasing the dielectric constant
- allows **decreasing the size** of the DRA by **increasing its dielectric constant**
- the **impedance bandwidth** is **inversely proportional** to the relative permittivity of the DR.

Resonant frequency of a cylindrical DRA with radius a = 2.5 cm and height h = 5 cm as a function of the relative dielectric constant

DRA Analysis

❑ Cylindrical DRA:



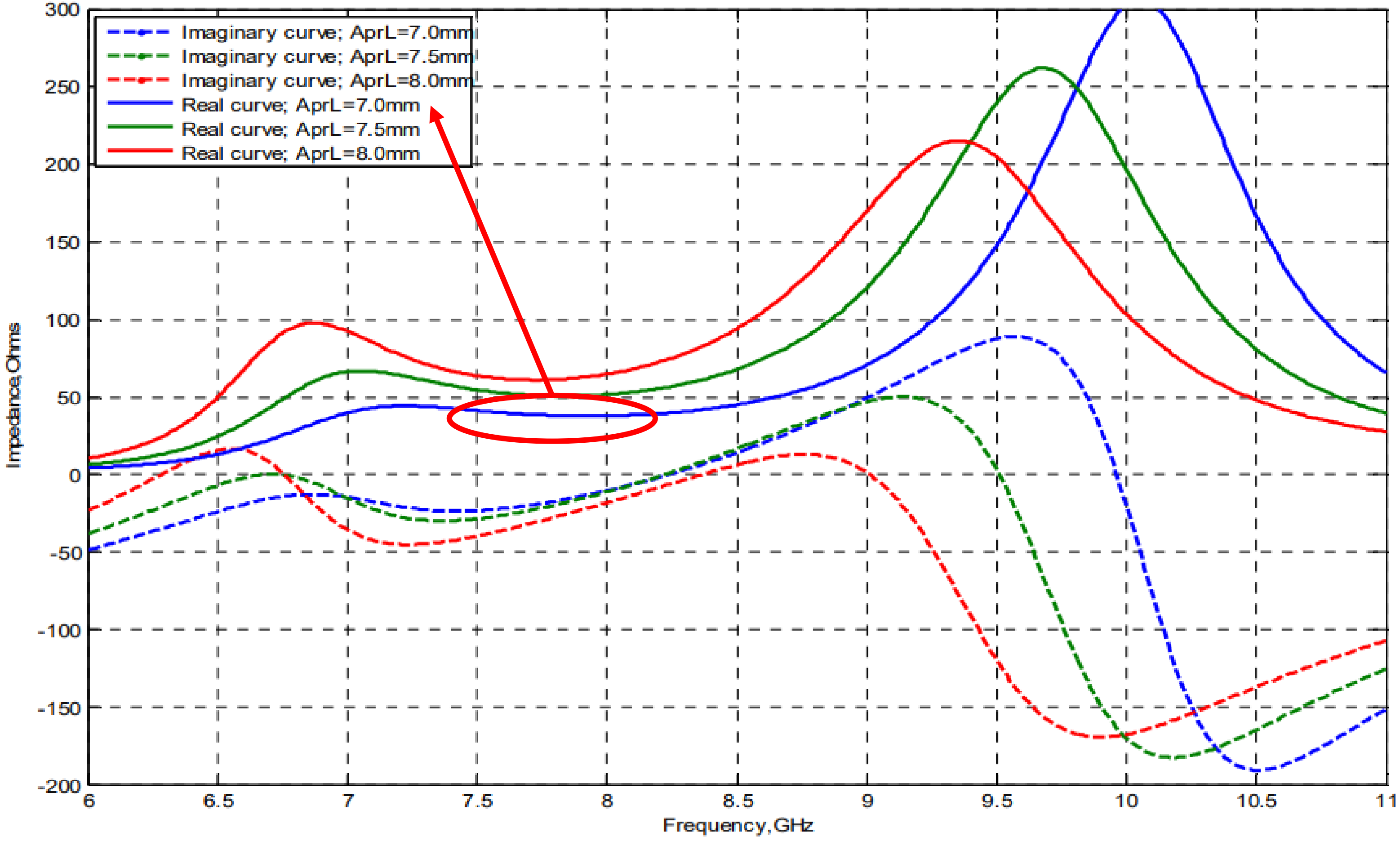
- DR Resonant freq.: 7.3 GHz
- DR Height: 4.7mm (H)
- DR Diameter: 10mm (D)
- DR ε_r: 6
- substrate h: 0.508mm
  substrate ε_r: 3.38.
- feed line: microstrip
- feed line width: 1 mm
- feed line char. impd.: 50Ω
- Slot: rectangular slot (inductive coupling)
- Ground plane: 40mm*40mm.

Figure 3.1 Rectangular shaped aperture slot located at the DRA centre (a) Top view (b) Side view

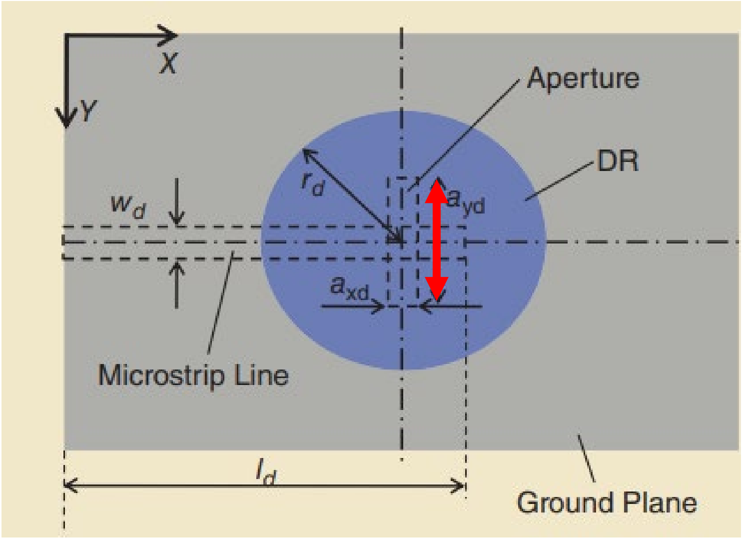
DRA Analysis

❑ Cylindrical DRA:

Family of impedance curves representing different slot lengths



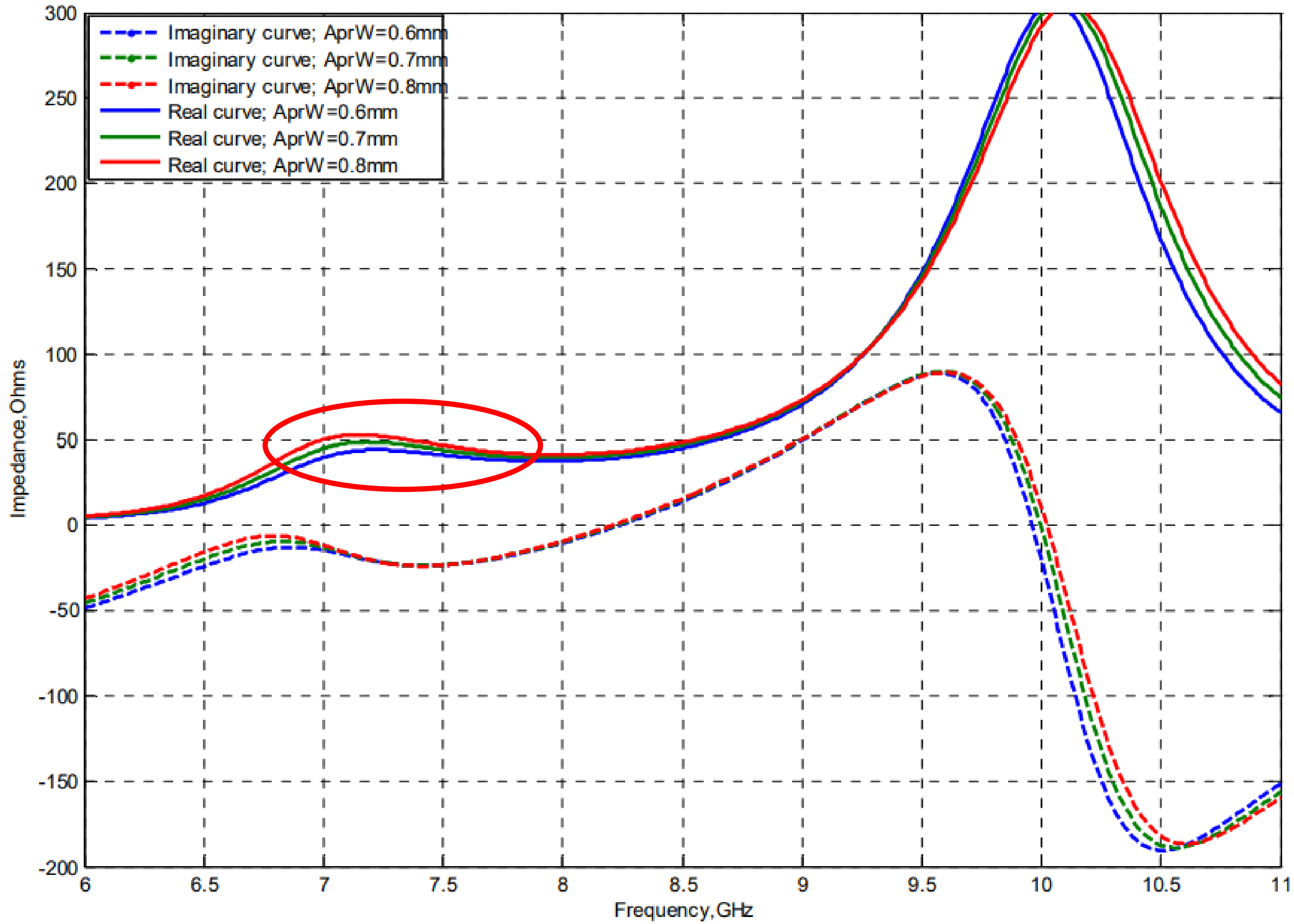
- For **7mm aperture length** around 7 GHz the imaginary part correspond to nearly 50 Ohms of the real part.
- aperture length of 7mm is assumed to be suitable to make DRA resonate



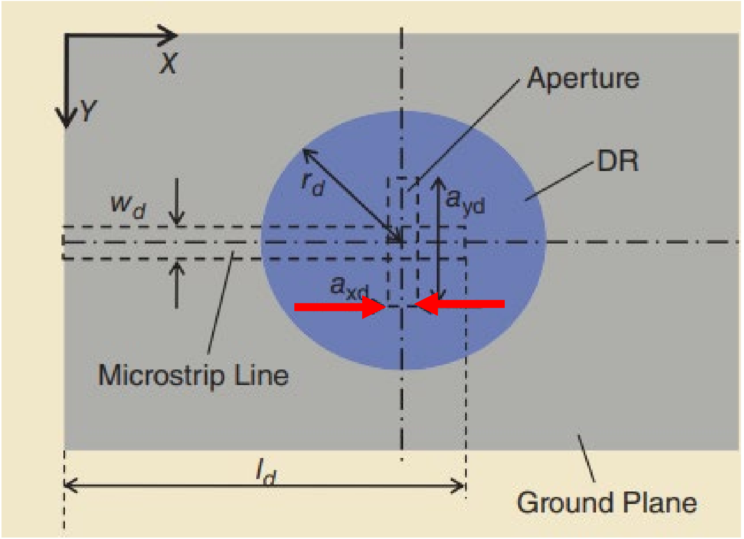
DRA Analysis

❑ Cylindrical DRA:

Set of impedance curves representing different slot widths



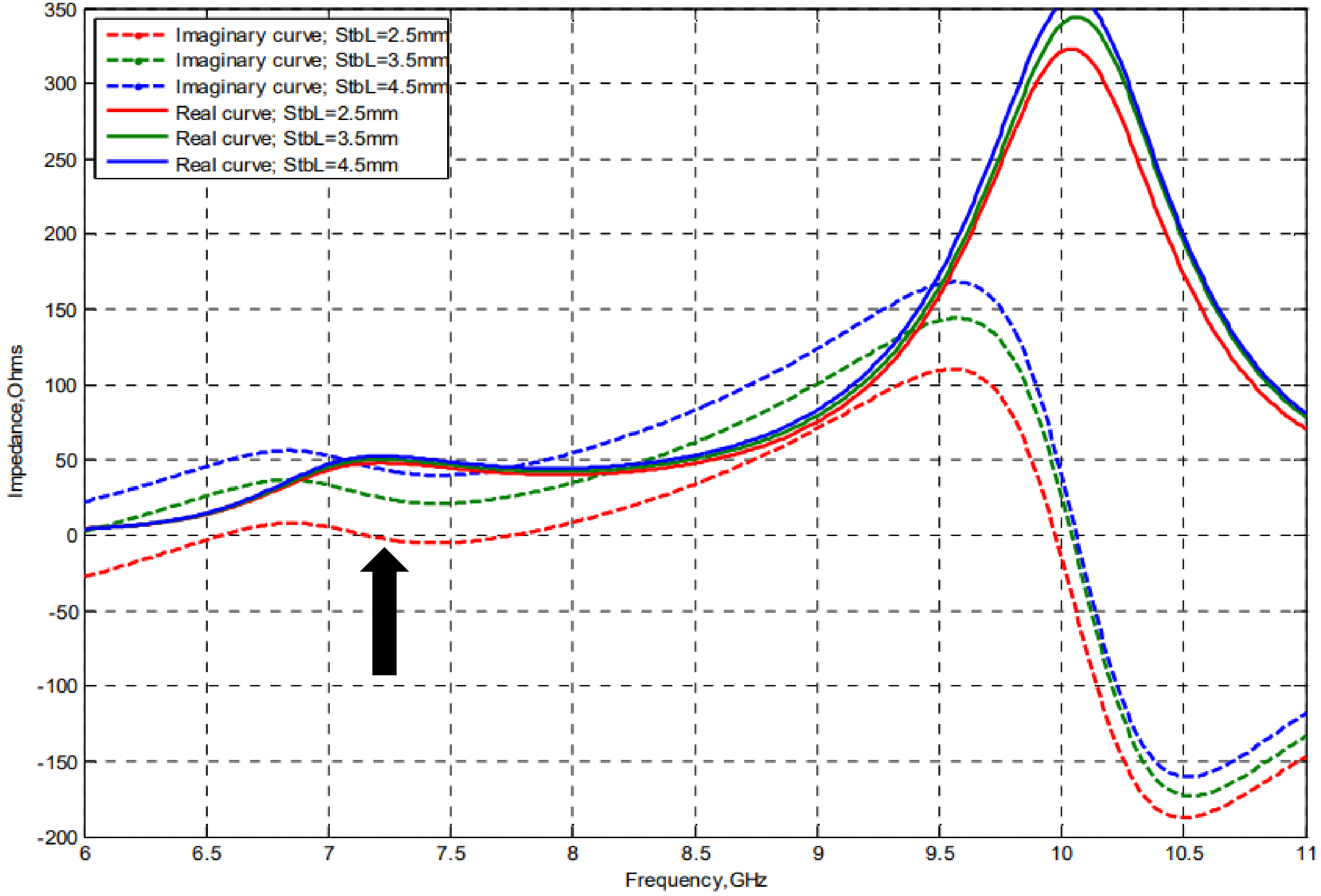
- **slot widths** do not greatly influence the DRA resonance
- **0.6mm** is chosen as slot width for this antenna



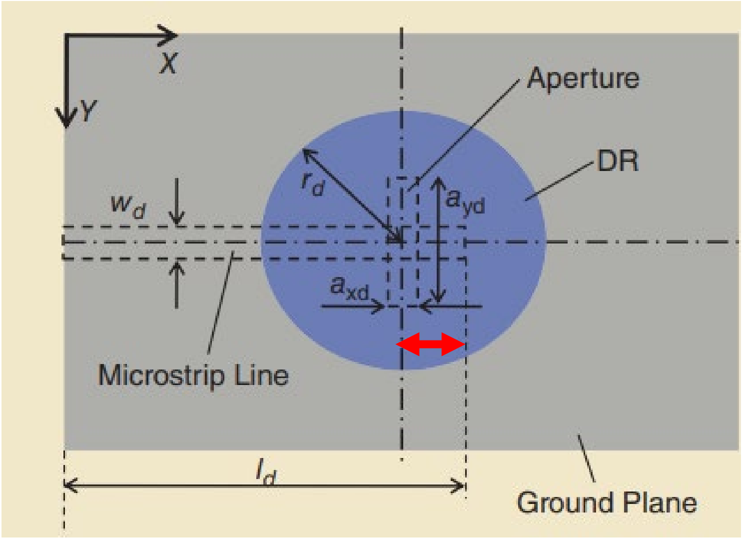
DRA Analysis

❑ Cylindrical DRA:

Set of impedance curves representing different **stub lengths**



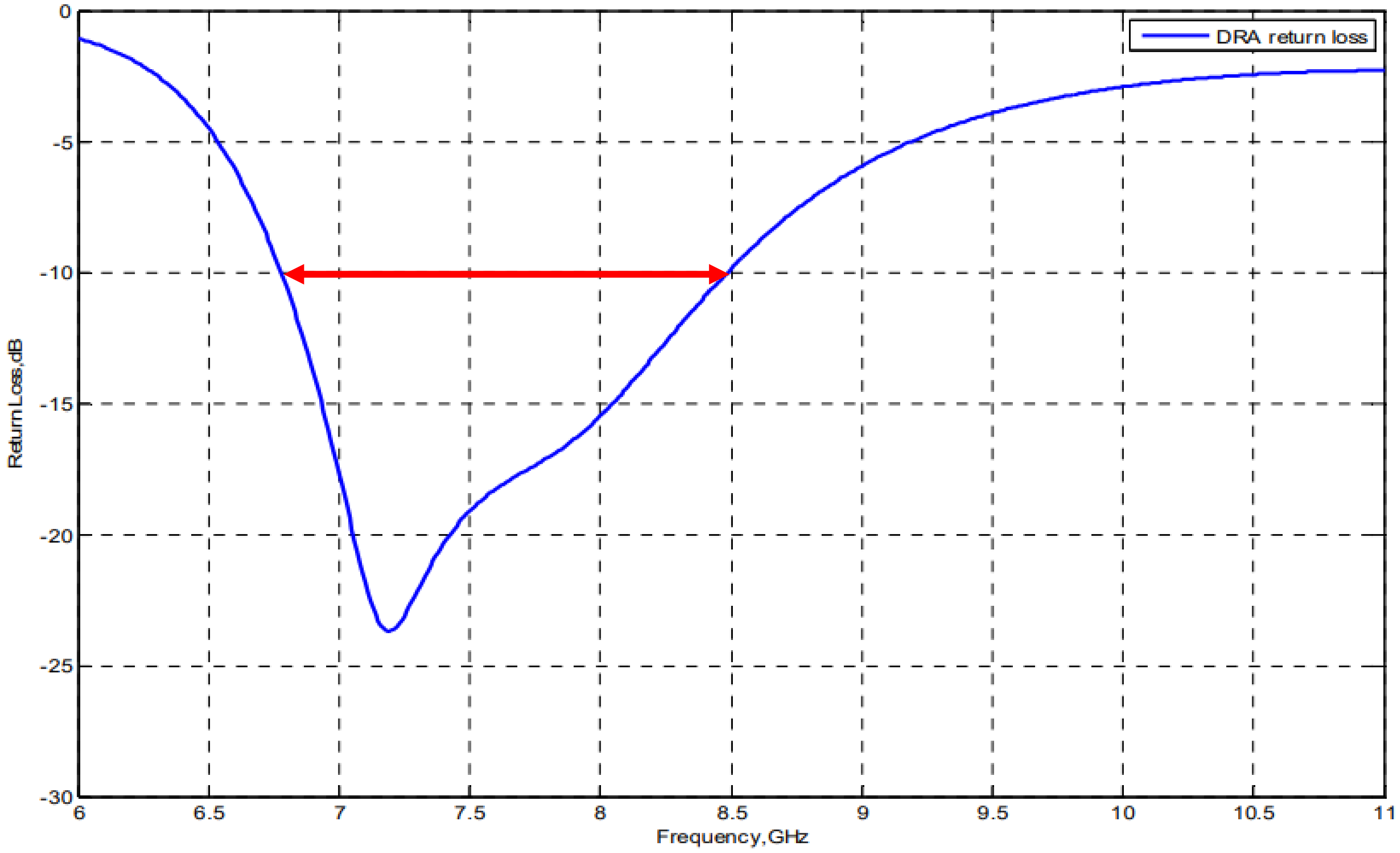
- An **extended quarter wave length stub** (λg/4) improving the coupling
- **reactance cancels the reactance of the aperture slot**
- **stub length of 2.5mm** nullifies the reactance parts at 7.3 GHz.



DRA Analysis

❑ Cylindrical DRA:

return loss curve of the final design

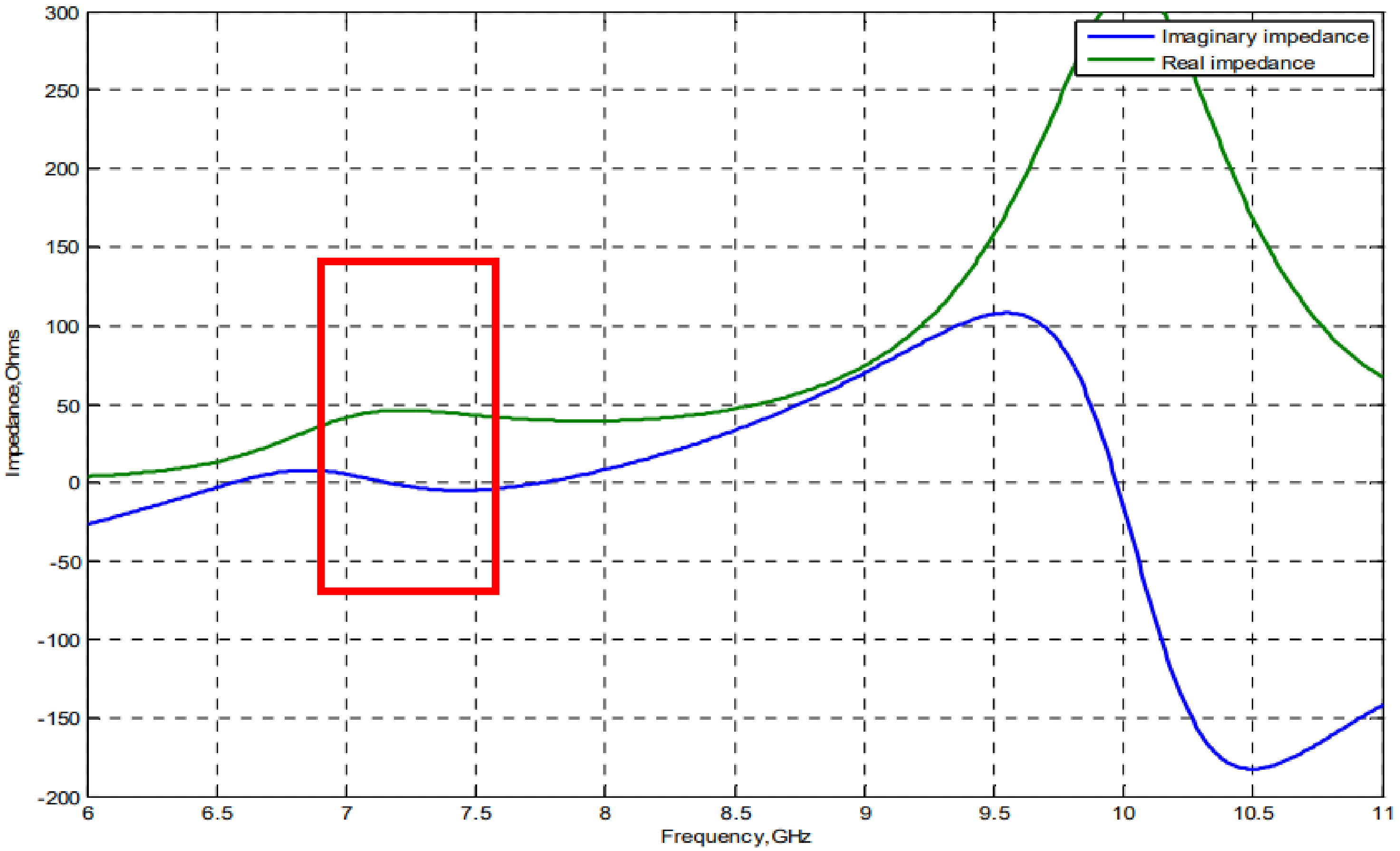


- simulated -10dB return loss (6.75GHz-8.5GHz) result
- offers an impedance bandwidth of 22%.

DRA Analysis

❑ Cylindrical DRA:

The impedance curves of the final design

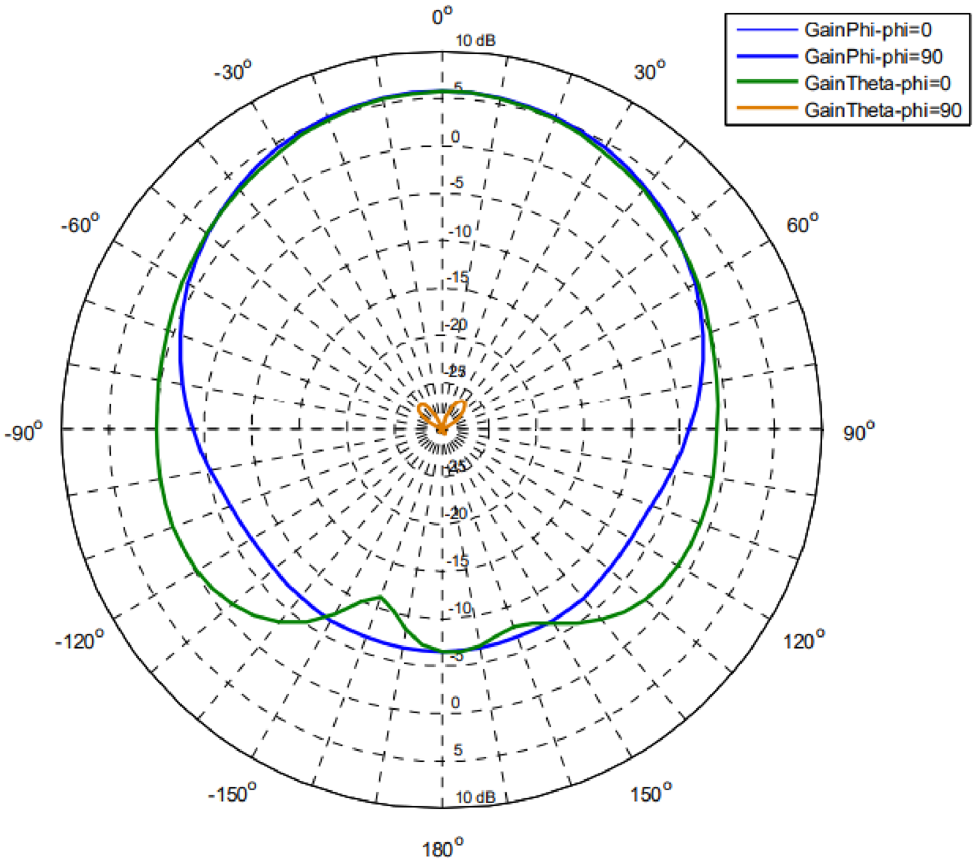


- imaginary part of the impedance is close to zero
- real part is around 50 Ohms.

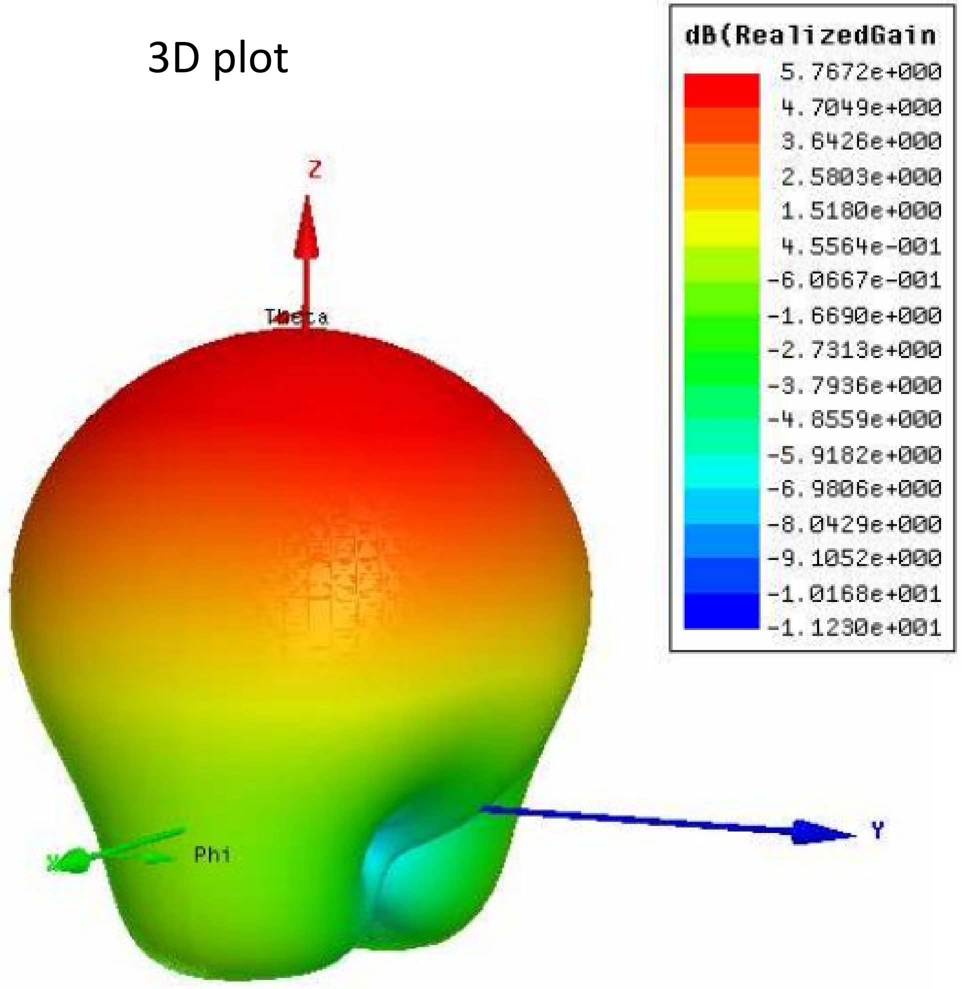
DRA Analysis

❑ Cylindrical DRA:

Broadside pattern



3D plot



DRA Design Example Performance

❑ **Cylindrical DRA:**

- The co-pol level in both planes nearly 30dB higher than the cross-pol in the broad direction.
- a gain of 5.7 dBi
- radiation efficiency of 98%
- front to back ratio (F/B) in both planes is estimated to be 12dB
- The radiation patterns stable with nearly same pattern shapes ranging from 7GHz to 8GHz

Design Principles of DRA

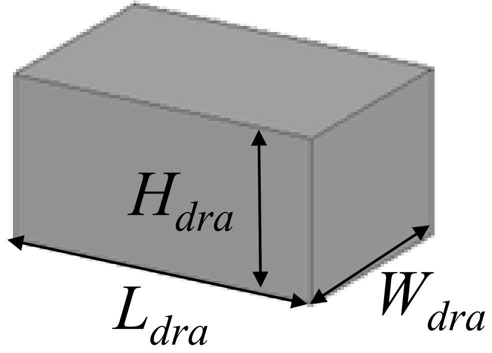
❑ Rectangular DRA:

$$f_{GHz} = \frac{15\,F}{\pi w_{dra\,(cm)}\sqrt{\varepsilon_{r,\,dra}}} \qquad (1)$$

$$F = x_0 + x_1\left(\frac{W_{dra}}{2H_{dra}}\right)^1 + x_2\left(\frac{W_{dra}}{2H_{dra}}\right)^2 \qquad (2)$$

$$x_0 = 2.57 - 0.8\left(\frac{L_{dra}}{2H_{dra}}\right)^1 + 0.42\left(\frac{L_{dra}}{2H_{dra}}\right)^2 - 0.05\left(\frac{L_{dra}}{2H_{dra}}\right)^3$$

$$x_1 = 2.71\left(\frac{L_{dra}}{2H_{dra}}\right)^{-0.282}, \quad x_2 = 0.16$$



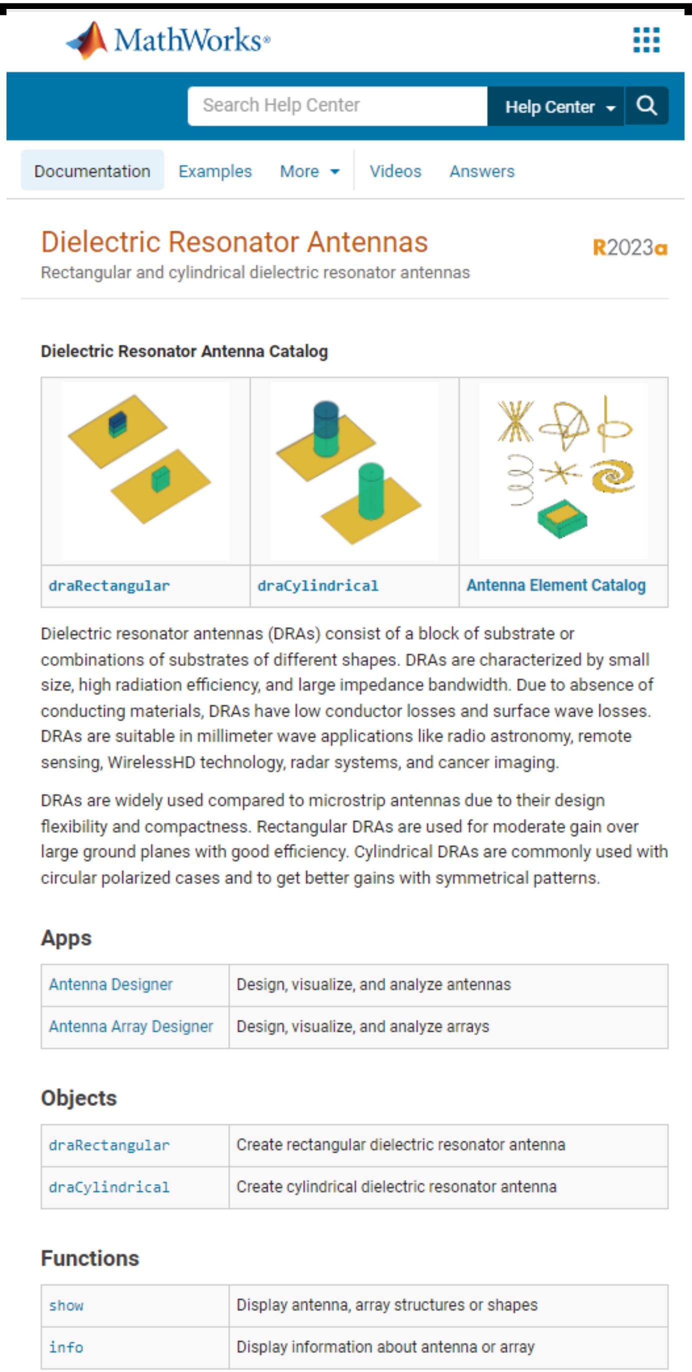
Where, f_{GHz} is resonant frequency, F is normalized frequency, $\epsilon_{r,\,dra}$ is permittivity of cubic DR and W_{dra}, L_{dra} & H_{dra} are width, length & height of the DR in cm.

Design Principles of DRA

❑MATLAB

https://www.mathworks.com/help/antenna/dra.html

- Dielectric resonator antennas (DRAs) are made of substrate blocks of different shapes.
- DRAs have small size, high radiation efficiency, and large impedance bandwidth.
- DRAs have low conductor losses and surface wave losses due to the absence of conducting materials.
- DRAs are suitable for millimeter wave applications like radio astronomy, remote sensing, WirelessHD technology, radar systems, and cancer imaging.
- DRAs offer design flexibility and compactness compared to microstrip antennas.
- Rectangular DRAs are used for moderate gain over large ground planes with good efficiency.
- Cylindrical DRAs are commonly used with circular polarized cases and to get better gains with symmetrical patterns.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Dielectric Resonator Antennas R2023a

Rectangular and cylindrical dielectric resonator antennas

Dielectric Resonator Antenna Catalog

draRectangular	draCylindrical	Antenna Element Catalog

Dielectric resonator antennas (DRAs) consist of a block of substrate or combinations of substrates of different shapes. DRAs are characterized by small size, high radiation efficiency, and large impedance bandwidth. Due to absence of conducting materials, DRAs have low conductor losses and surface wave losses. DRAs are suitable in millimeter wave applications like radio astronomy, remote sensing, WirelessHD technology, radar systems, and cancer imaging.

DRAs are widely used compared to microstrip antennas due to their design flexibility and compactness. Rectangular DRAs are used for moderate gain over large ground planes with good efficiency. Cylindrical DRAs are commonly used with circular polarized cases and to get better gains with symmetrical patterns.

Apps

Antenna Designer	Design, visualize, and analyze antennas
Antenna Array Designer	Design, visualize, and analyze arrays

Objects

draRectangular	Create rectangular dielectric resonator antenna
draCylindrical	Create cylindrical dielectric resonator antenna

Functions

show	Display antenna, array structures or shapes
info	Display information about antenna or array

Performance Improvement Techniques in DRA

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DOI: 10.1002/mmce.21270

REVIEW ARTICLE

WILEY INTERNATIONAL JOURNAL OF RF AND MICROWAVE COMPUTER-AIDED ENGINEERING

A state-of-art review on performance improvement of dielectric resonator antennas

Sounik Kiran Kumar Dash[1] | Taimoor Khan[1] | Yahia M. M. Antar[2]

[1] Department of Electronics and Communication Engineering, National Institute of Technology Silchar, Silchar, Assam, India

[2] Department of Electrical and Computer Engineering, Royal Military College of Canada, Kingston, Ontario, Canada

Correspondence
Taimoor Khan, Department of Electronics and Communication Engineering, National Institute of Technology Silchar, Silchar, Assam, India.

Abstract

This article outlines a compressive review on investigation carried out targeting to gain, circular polarization (CP), and mutual coupling red antenna (DRA). The DRA has already been created a engineering domain because of its adept characteristics high efficiency, low-loss, and mainly 3D-design flexibil in conventional antennas. In this context, the research o and mutual coupling are quite interesting and being carrie ades. The ultimate aim of this article is to (i) give an over adopted in context to gain, CP, and mutual coupling rec sive review of notable research carried out targeting to th (iii) find out the research gap concentration for furtheranc

[a]

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DOI: 10.1002/mmce.21701

REVIEW ARTICLE

INTERNATIONAL JOURNAL OF RF AND MICROWAVE COMPUTER-AIDED ENGINEERING WILEY

Recent developments in bandwidth improvement of dielectric resonator antennas

Sounik Kiran Kumar Dash[1] | Taimoor Khan[2]

[1] Department of Electronics and Communication Engineering, CHRIST (Deemed-to-be University), Bengaluru, India

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Abstract

This article shows a compressed chronological overview of dielectric resonator antennas (DRAs) emphasizing the developments targeting to bandwidth performance characteristics in last three and half decades. The research articles available in open literature give strong information about the innovation and rapid developments of DRAs since 1980s. The sole intention of this review article is to, (a) highlight the novel researchers and to analyze their effective and innovative research carried out on DRA for the furtherance of its performance in terms of only bandwidth and bandwidth with other characteristics, (b) give a practical prediction of future of DRA as per the past and current state-of-art condition, and (c) provide a conceptual support to the antenna modelers for further innovations as well as miniaturization of the existing ones. In addition some of the significant observations made

[b]

Different Applications of DRA

Dielectric resonator antenna (DRA) supports wide range of applications, such as;

- Different microwave bands
  - C band: 4 to 8 GHz
  - X band: 8 to 12 GHz
  - Ku band: 12 to 18 GHz
  - Ka band: 26.5 to 40 GHz
- Popular applications (WLAN, WiMAX, WiFi, Bluetooth, Radar, RFID, Sensor, Chip, etc)
- The detail applications are available in ref [a].

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DOI 10.1002/mmce.21069

REVIEW ARTICLE

WILEY INTERNATIONAL JOURNAL OF RF AND MICROWAVE COMPUTER-AIDED ENGINEERING

Dielectric resonator antennas: An application oriented survey

Sounik Kiran Kumar Dash[1] | Taimoor Khan[1] | Asok De[2]

[1]Department of Electronics & Communication Engineering, National Institute of Technology Silchar, India
[2]Department of Electronics & Communication Engineering, National Institute of Technology Patna, India

Correspondence
National Institute of Technology Silchar, India.
Email: ktaimoor@gmail.com

Abstract

This survey article outlines a comprehensive investigation of research carried out on dielectric resonator antennas (DRAs) in the last three and half decades, in an application-oriented approach. DRAs have created a remarkable position in antenna engineering for their adept characteristics like high efficiency, low loss, wide bandwidth, compact size, 3-dimensional modeling flexibility, etc. The use of DRAs for different commercial and defense applications associated with the wireless communication is highlighted in this article. To make a smooth and effective survey article, all the application-oriented DRAs available in the open literature are classified in five different categories like microwave bands, specific frequency, technology, millimeter-wave, and miscellaneous types. The ultimate aims of this review article are as follows: (i) highlights the usability of DRAs for different commercial and defense applications, (ii) helpful for the antenna industries/manufacturers to find out the best DRA for any specific application as per their requirement, and (iii) points out research gap in some application domains which will be quite helpful for future antenna researchers. In the authors' opinion, this survey may be helpful to DRA researchers as such a survey process is not available in the open literature.

KEYWORDS
antenna survey, antenna review, dielectric resonator, different applications, DRA, DR-antenna

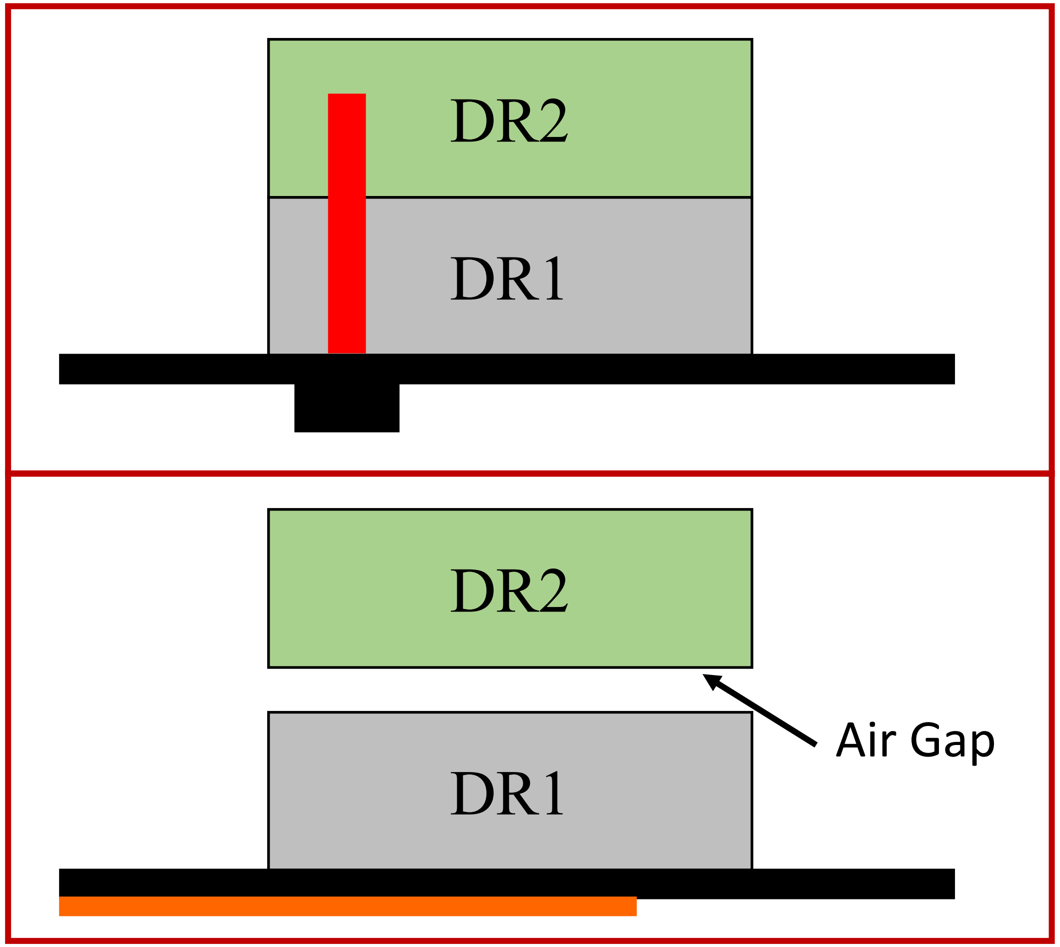
[a]

Performance Improvement Techniques in DRA

Bandwidth Improvement Techniques:

1) Stacking:

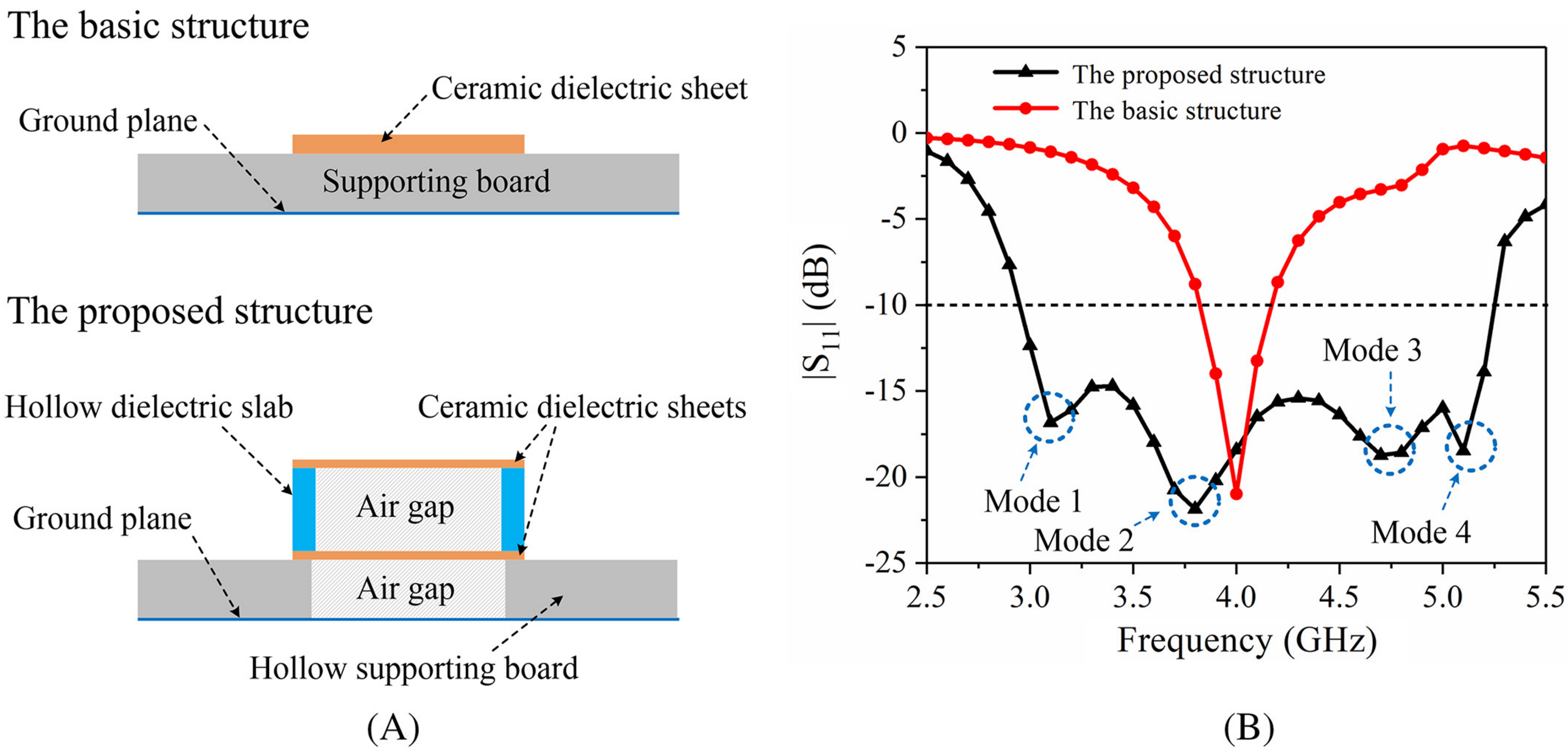
- placement of one DR upon another DR.
- In this case,
  - two DRs have two resonant frequencies
  - when stacked dual resonance concept works out for broadening the antenna bandwidth. [9]
  - This technique can be extended for triple/multiple stacking in-order to further enhance the bandwidth.
- extended by air intrusion between the DRs [10]



Performance Improvement Techniques in DRA

Bandwidth Improvement Techniques:

1) Stacking:



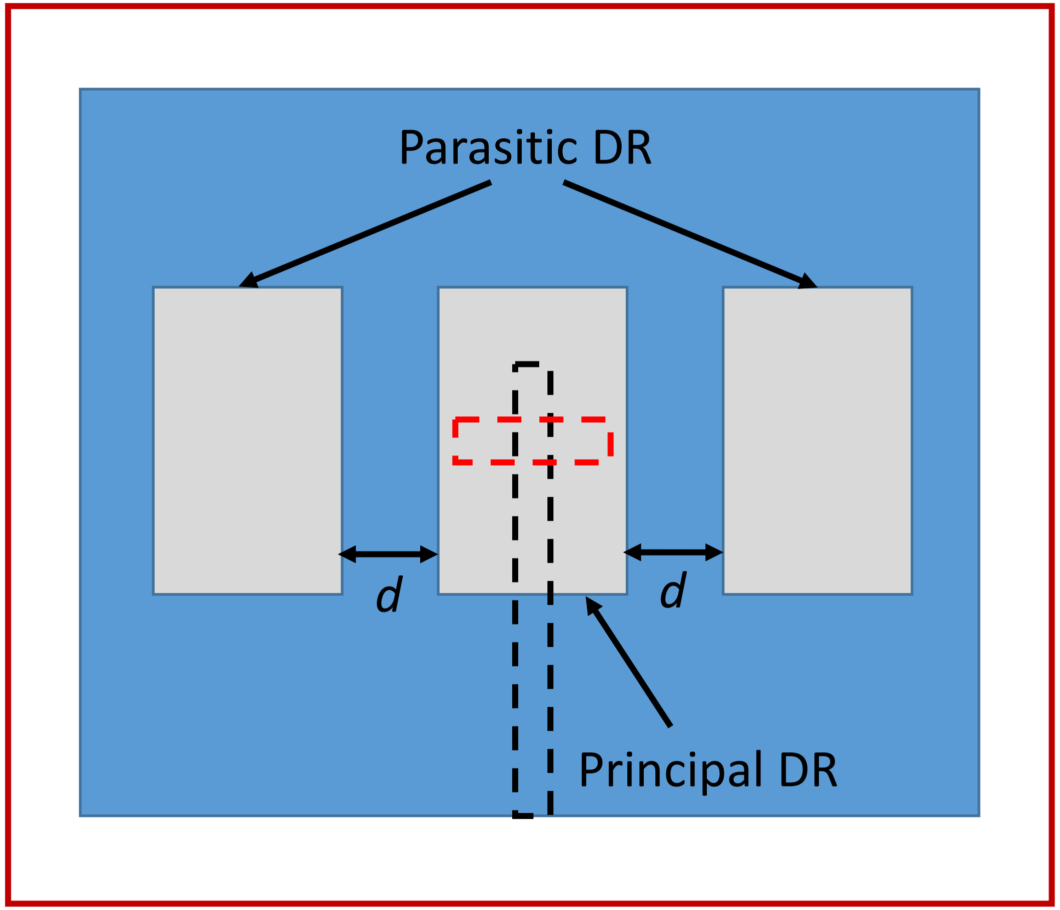
Sun, W-J, Yang, W-W, Chu, P, Chen, J-X. A wideband stacked dielectric resonator antenna for 5G applications. *Int J RF Microw Comput Aided Eng*. 2019; 29:e21897. https://doi.org/10.1002/mmce.21897

Performance Improvement Techniques in DRA

Bandwidth Improvement Techniques:

2) Parasitic Coupling:

- Means, there will be one principal DRA and some parasitic DRS. Parasitic DRs gets excited by the principal DR.
- When other elements with different resonant frequencies are introduced to both/all sides of the principal element they can also be efficiently excited near their own resonant frequencies through mutual coupling between elements.
- The relative level of excitation for each element is determined by the relative dimensions of the DRs, their positions relative to the centre of the slot. [11]

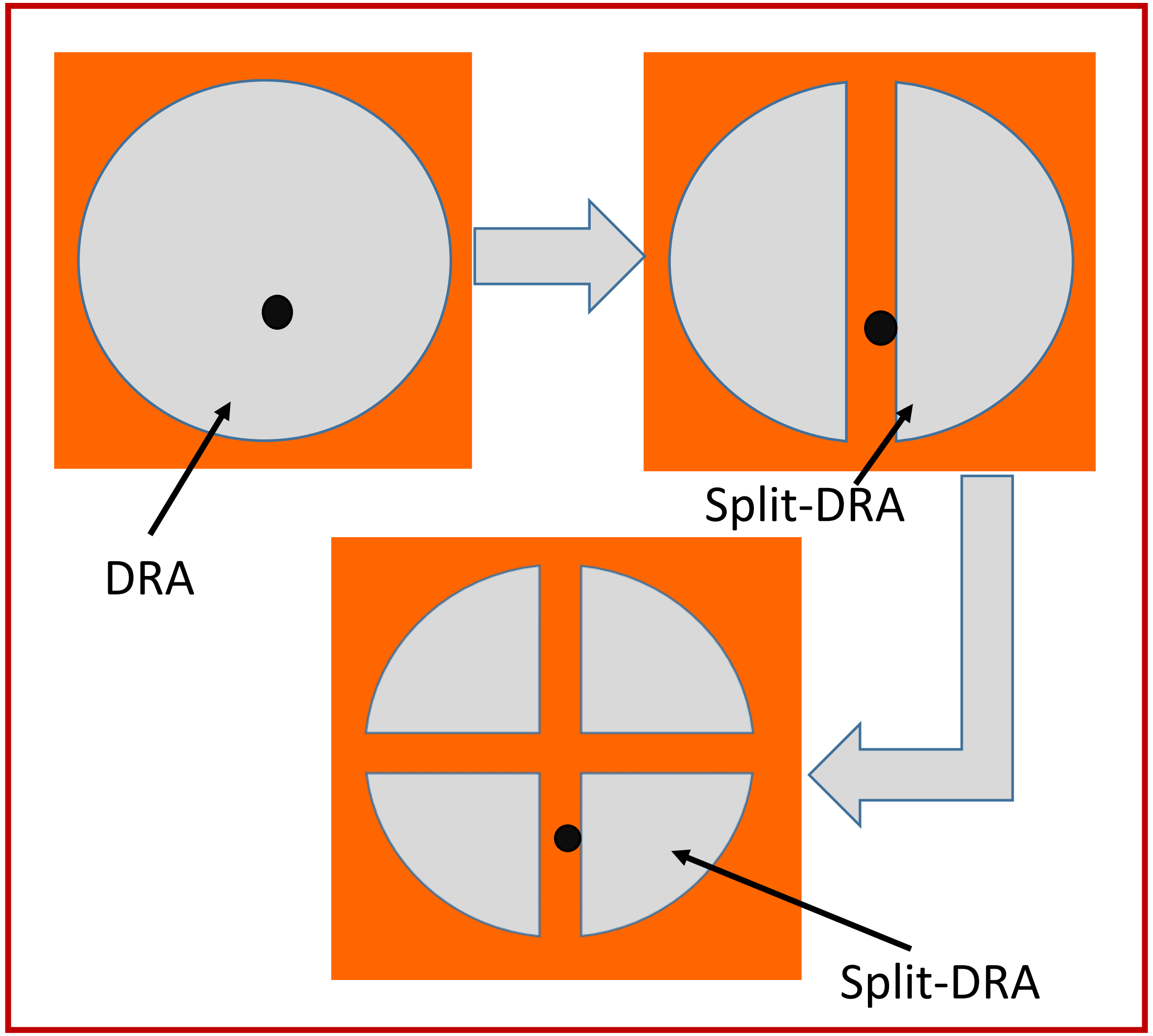


Performance Improvement Techniques in DRA

Bandwidth Improvement Techniques:

3) Splitting DR/Segmented DR:

- Breaking the regular shape of the DRA and inserting air gap there.
- Inserting air gap in between the structure affects the DR modes.
- Removal of dielectric material from where the electric field is strong incurs a significant increase in resonant frequency.
- The abrupt change of normal electric field across the discontinuities reduces the Q-factor and increases the impedance bandwidth. [12], [13]

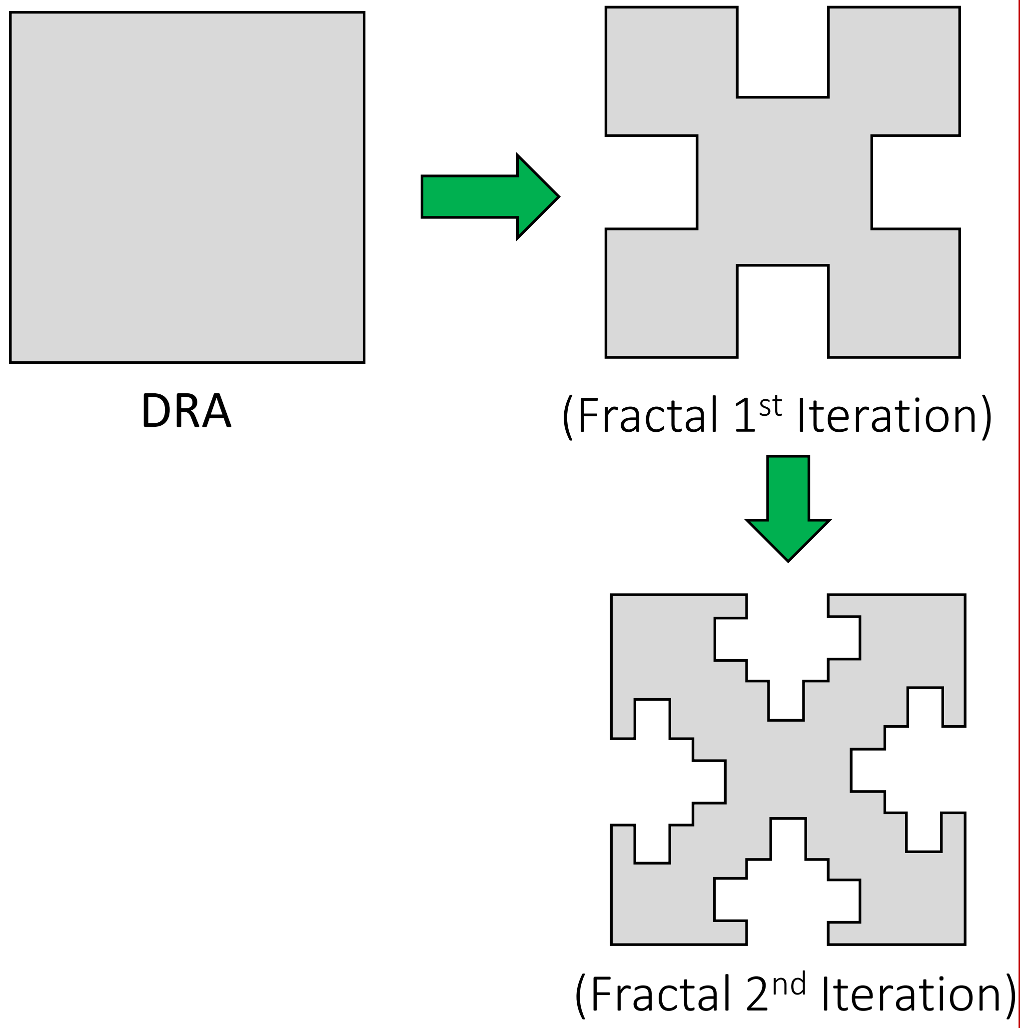


Performance Improvement Techniques in DRA

Bandwidth Improvement Techniques:

4) Fractal DR:

- A self-similar design to maximize the effective length, or increase the perimeter (on inside sections or the outer structure)
- Fractal concept defines the increase of electrical length with decrease in volume by the occurrence of similar pattern in a reduced manner.
- Popular concept as it exploits compactness and multiband characteristics.
- note that, the increase in number of iteration lowers the Q-factor and improves bandwidth.
- The incorporation of this concept in DRA reported firstly by *Hajihashemi and Abiri* [14].

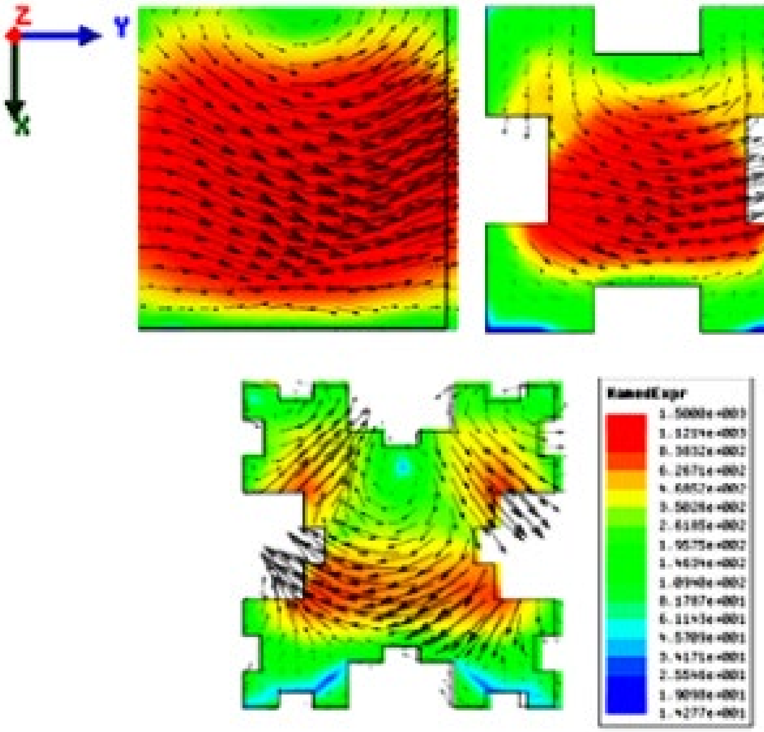


Performance Improvement Techniques in DRA

Bandwidth Improvement Techniques:

4) Fractal DR:

- It is evident that for the rectangular geometry the magnetic current exists almost entirely on the surface but as we increase the iteration, the surface current is confined towards the centre of the DRA thus reducing the effective dimensions of the antenna which results in an increase in the resonant frequency.



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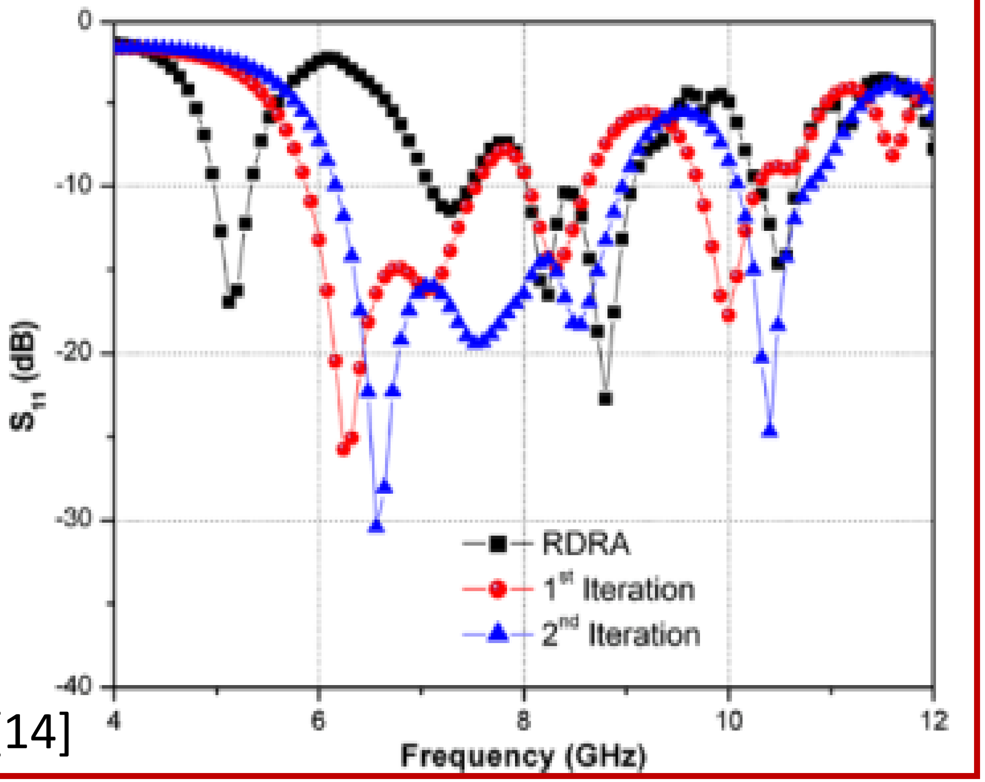
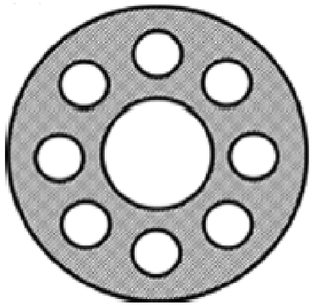
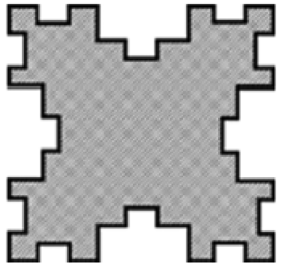
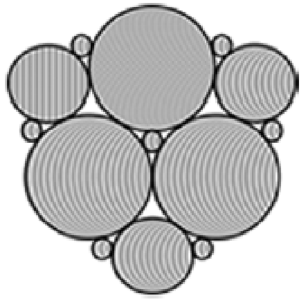




(Sierpinski)



(Minkowski)



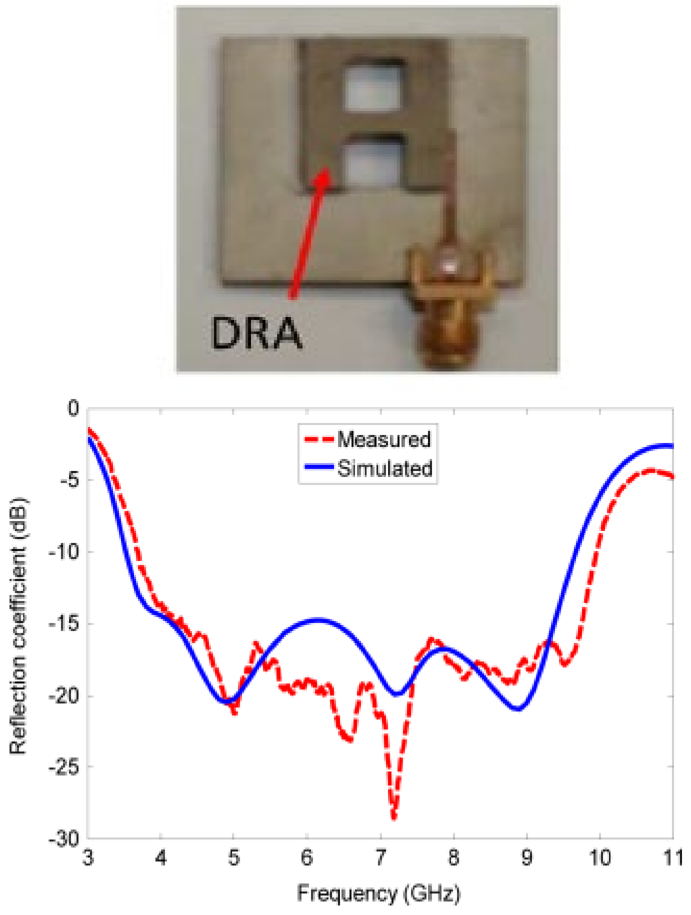
(Apollonian Gasket)

Performance Improvement Techniques in DRA

Bandwidth Improvement Techniques:

5) Hybrid DR / Super Shaped DR / A-Shape:

- Researchers have also investigated some hybrid shaped and super shaped DR for wideband operation.



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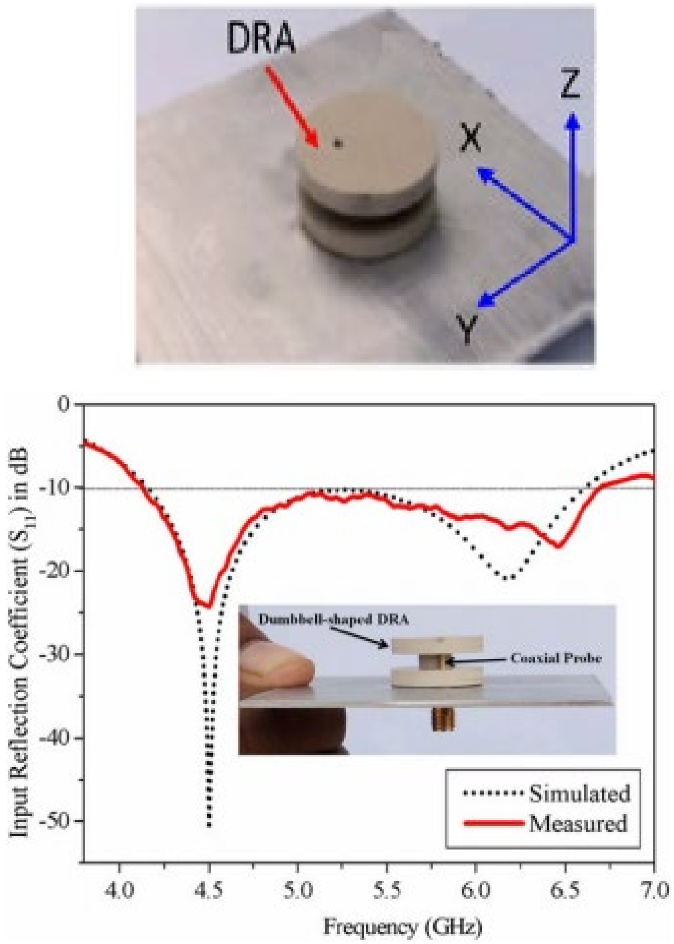
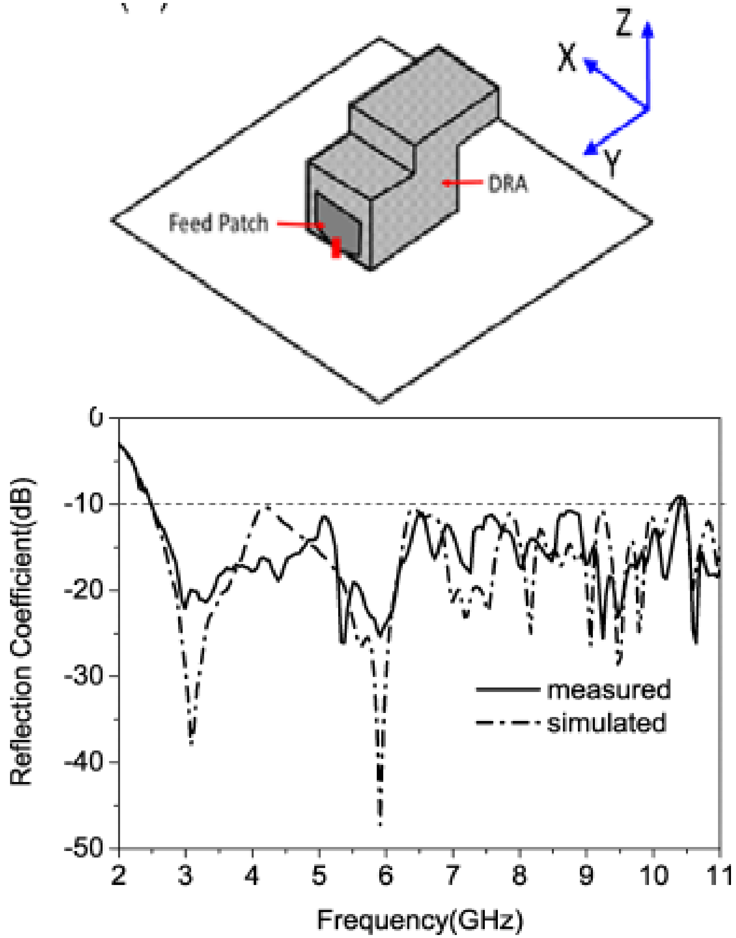


[16]



[17]

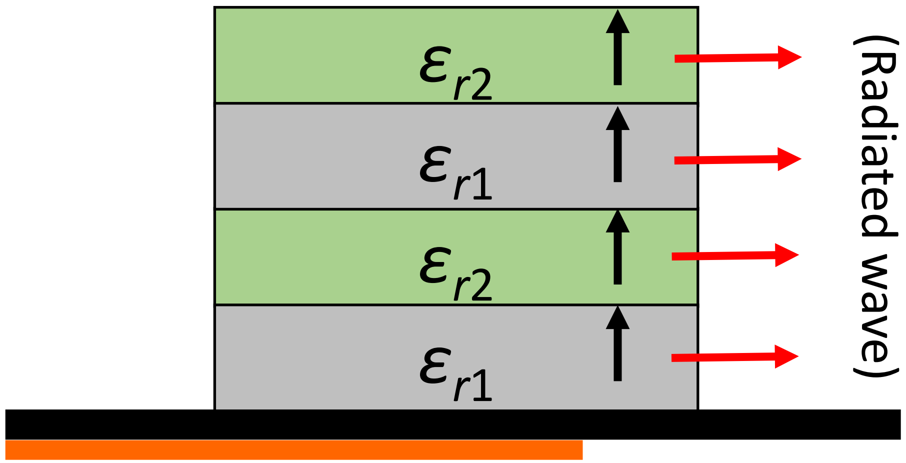
Performance Improvement Techniques in DRA

Gain Improvement Techniques:

- There are multiple techniques that have been employed in increasing the gain/directivity of the DRA.

1) Anisotropic Stacking of DR:

- placement of one DR upon another DR, and **each DRs relative permittivity should be different**.
- When electromagnetic waves move from one DR region to another DR region of different permittivity, then most of the waves started **radiating from side walls** than the top side.
- The increases of radiation from side walls compared to their top walls leads to the improvement of boresight* gain/directivity. [18], [19]



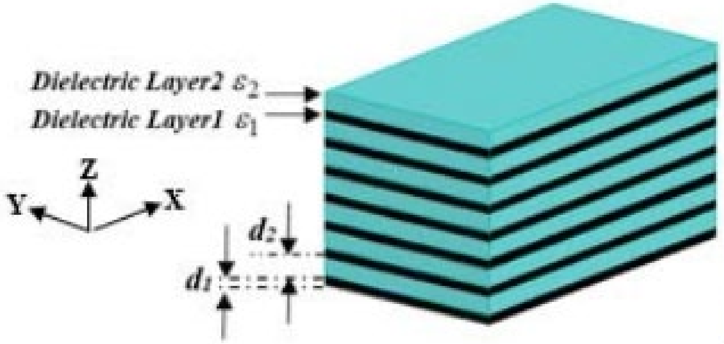
*antenna boresight is the axis of maximum gain

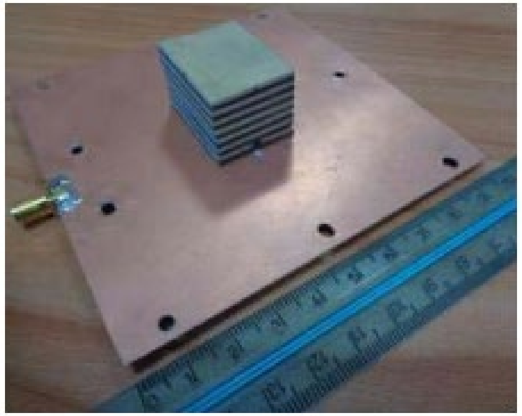
Performance Improvement Techniques in DRA

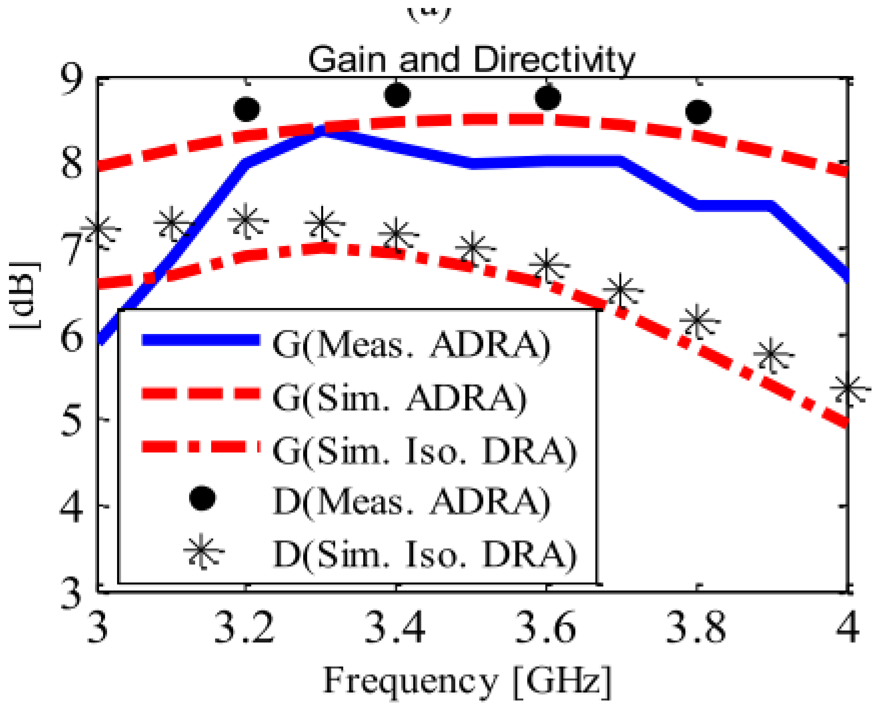
Gain Improvement Techniques:

- There are multiple techniques that have been employed in increasing the gain/directivity of the DRA.

1) Anisotropic Stacking of DR:







Gain and directivity of Anisotropic DRA compared with isotropic DRA.

- increased directivity of rectangular DRA in the boresight direction.
- Improved gain of the ADRA compared to the isotropic DRA one

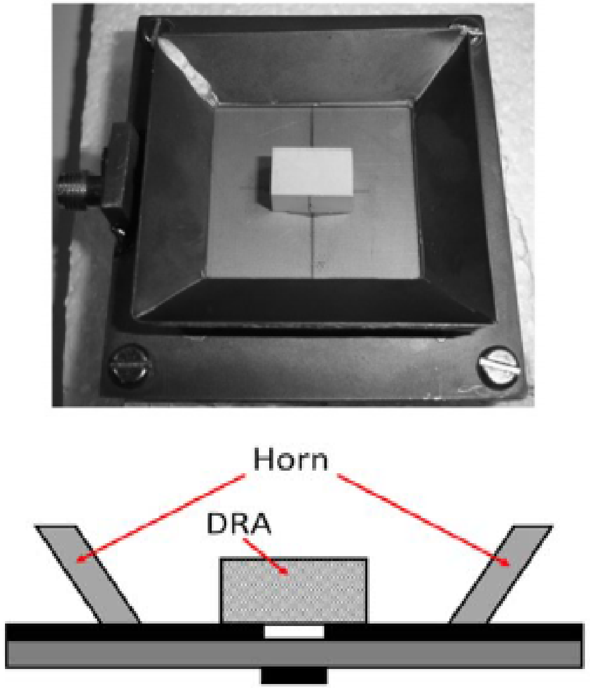
Fakhte, S. et al. "High Gain Rectangular Dielectric Resonator Antenna Using Uniaxial Material at Fundamental Mode." *IEEE Transactions on Antennas and Propagation* 65 (2017): 342-347.

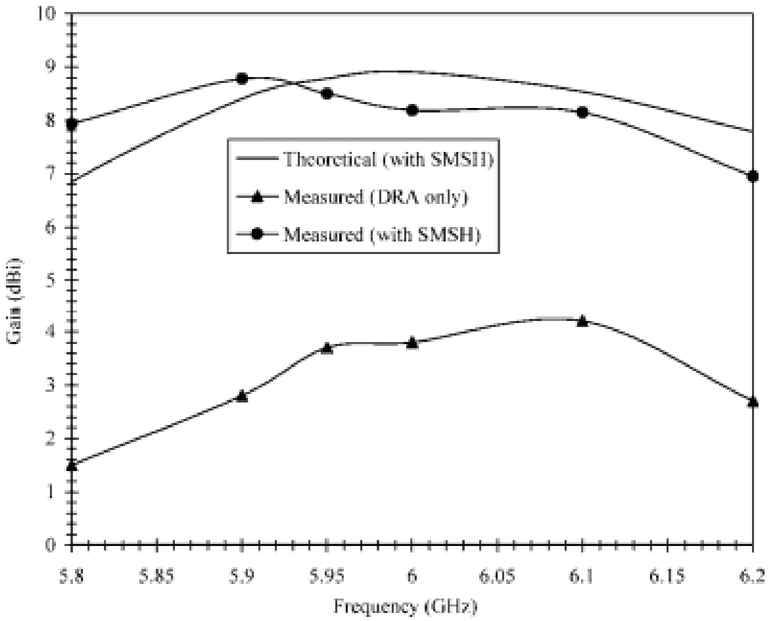
Performance Improvement Techniques in DRA

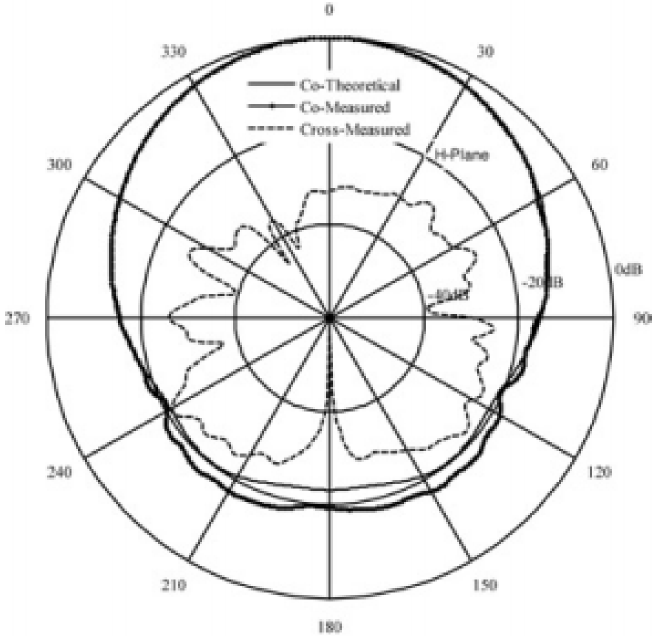
Gain Improvement Techniques:

2) Surface Mounted Short Horn (SMSH):

- In this case a short horn is placed around the DRA.
- helps in allowing most of the wave energy to radiate out the end of the horn into space in particular direction. [20]







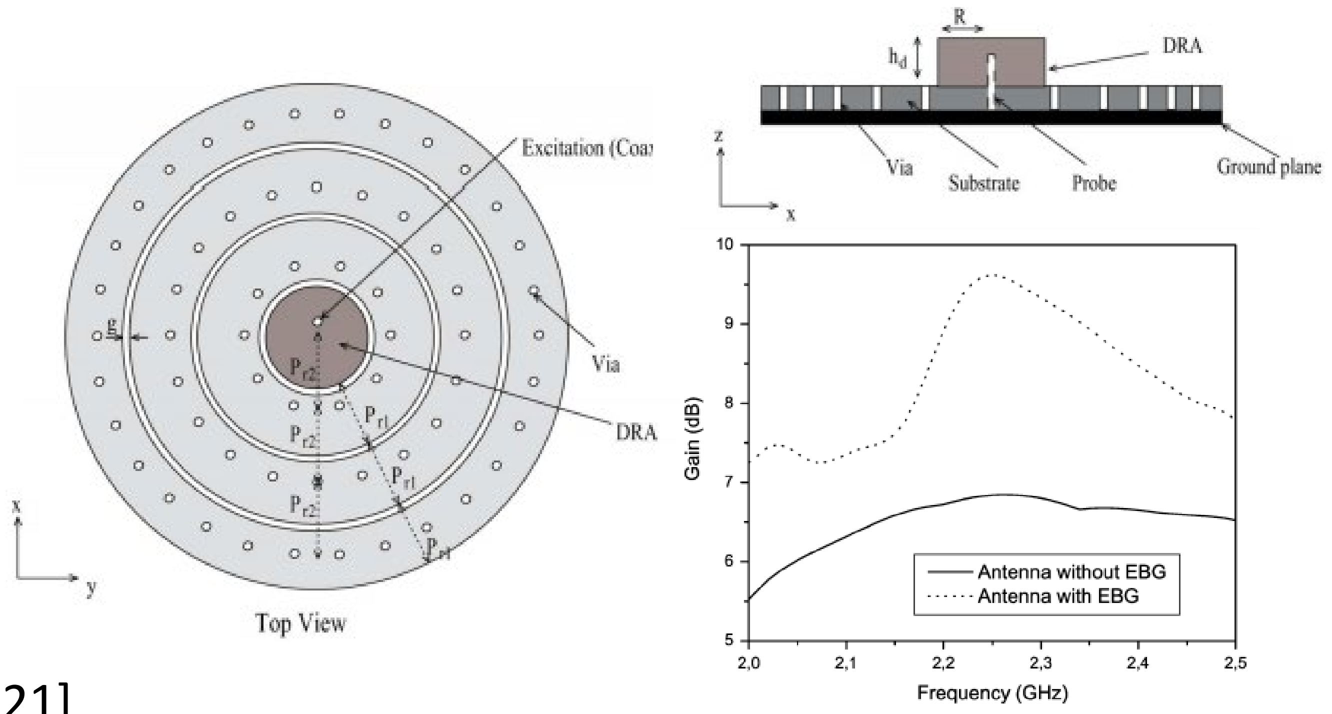
[20]

Performance Improvement Techniques in DRA

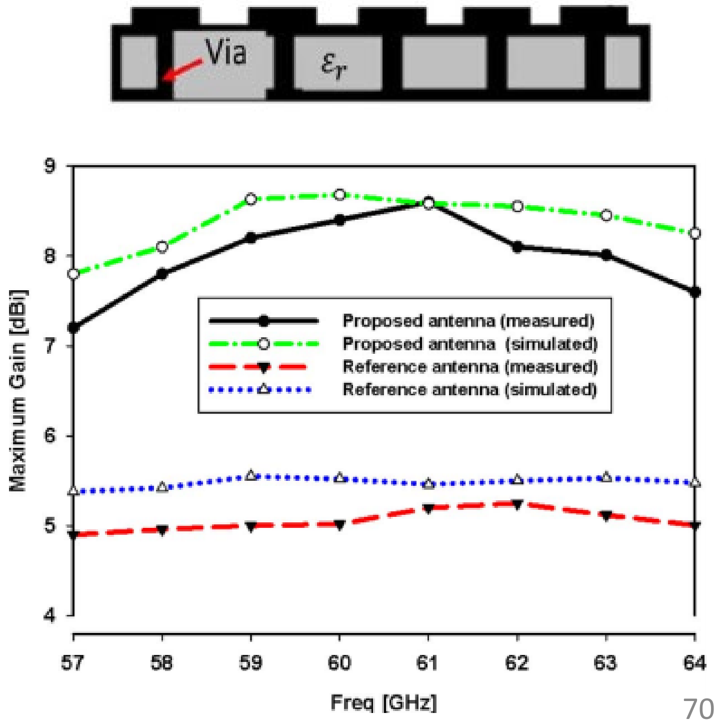
Gain Improvement Techniques:

3) Electromagnetic Bandgap (EBG) Loaded DRA:

- Utilized the concept of passive loading effect to enhance the gain of the antenna.
- EBG realized to reduce and eliminate surface waves, which leads to an increase in directivity, bandwidth and radiation efficiency.
- Also useful to reduce the side lobes of the radiation pattern and hence radiation pattern front-to- back ratio and overall antenna efficiency are improved [21], [22]



[21]



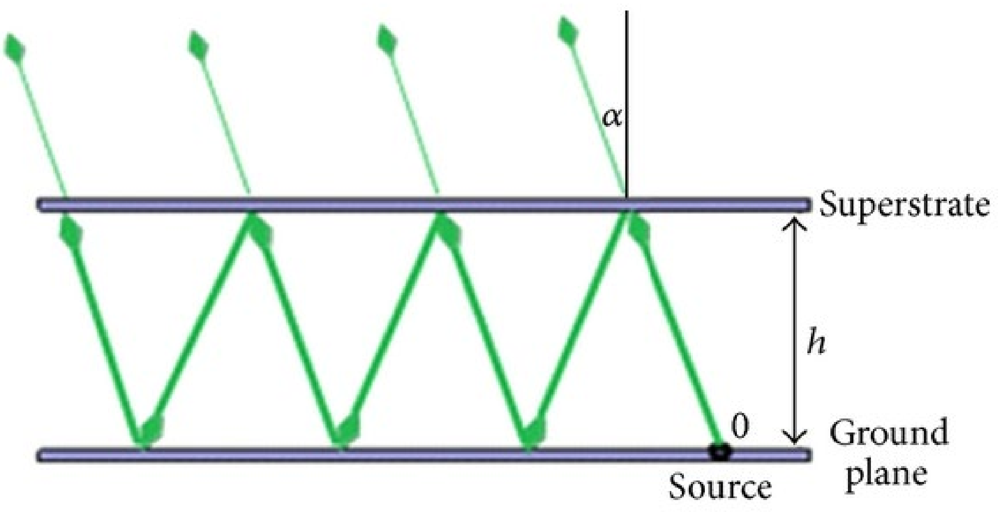
[22]

Performance Improvement Techniques in DRA

Gain Improvement Techniques:

4) Superstrate Loaded DRA:

- Utilize the concept of multiple reflection.
- The superstrate acts as a directive parasitic antenna, which considerably enhances the antenna gain.
- Here, Dielectric cover layers have been used to enhance the directivity of antennas that are over a ground plane, based on the multiple-reflection phenomenon.
- The effectiveness of this dielectric cover can be enhanced further by satisfying the resonance condition which is at a quarter wavelength air gap from the antenna element.



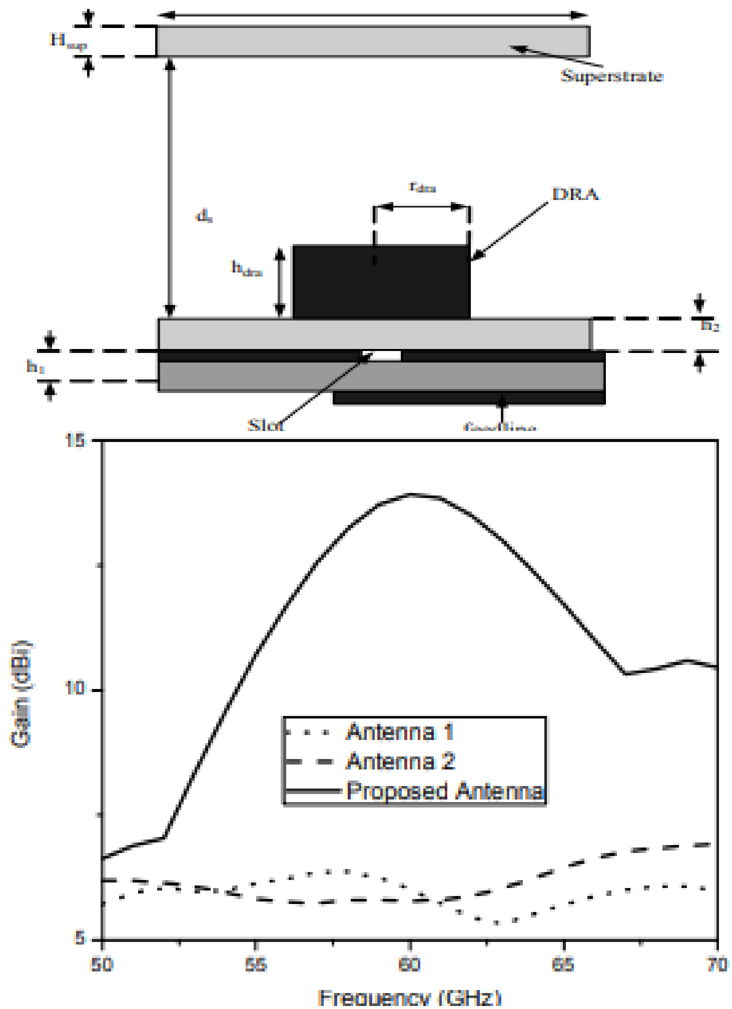
obtain high gain
at *α* direction, all
transmitted rays should be
in phase

Performance Improvement Techniques in DRA

Gain Improvement Techniques:

4) Superstrate Loaded DRA:

Dielectric Superstrate:



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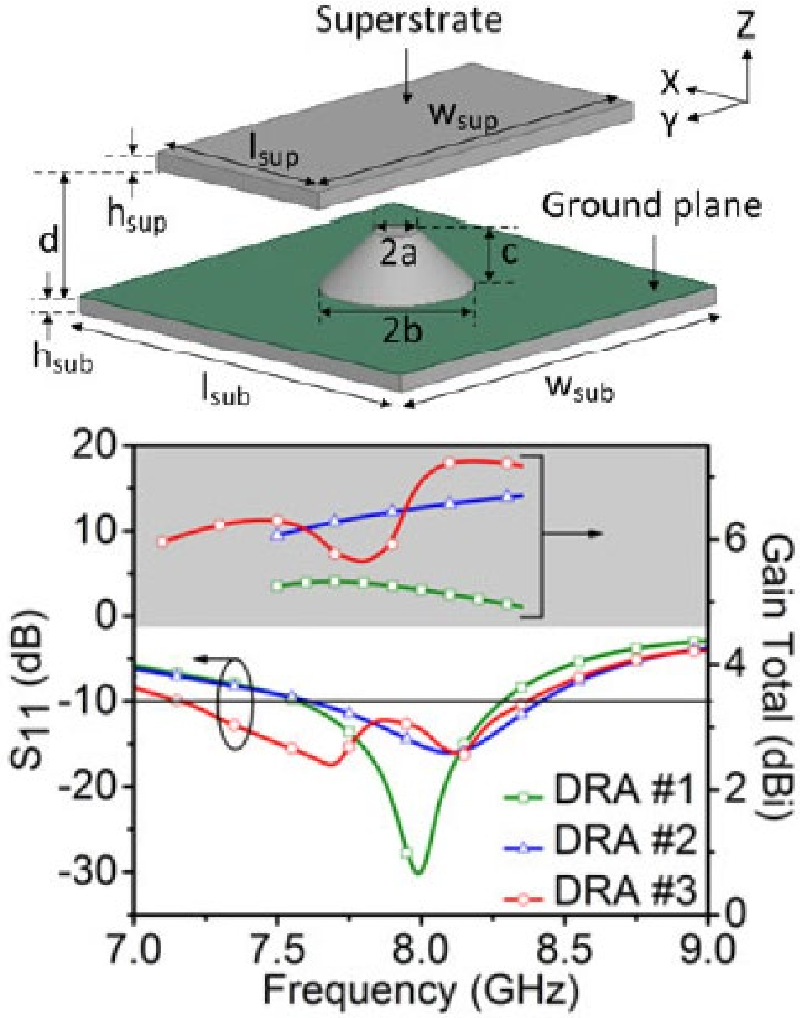


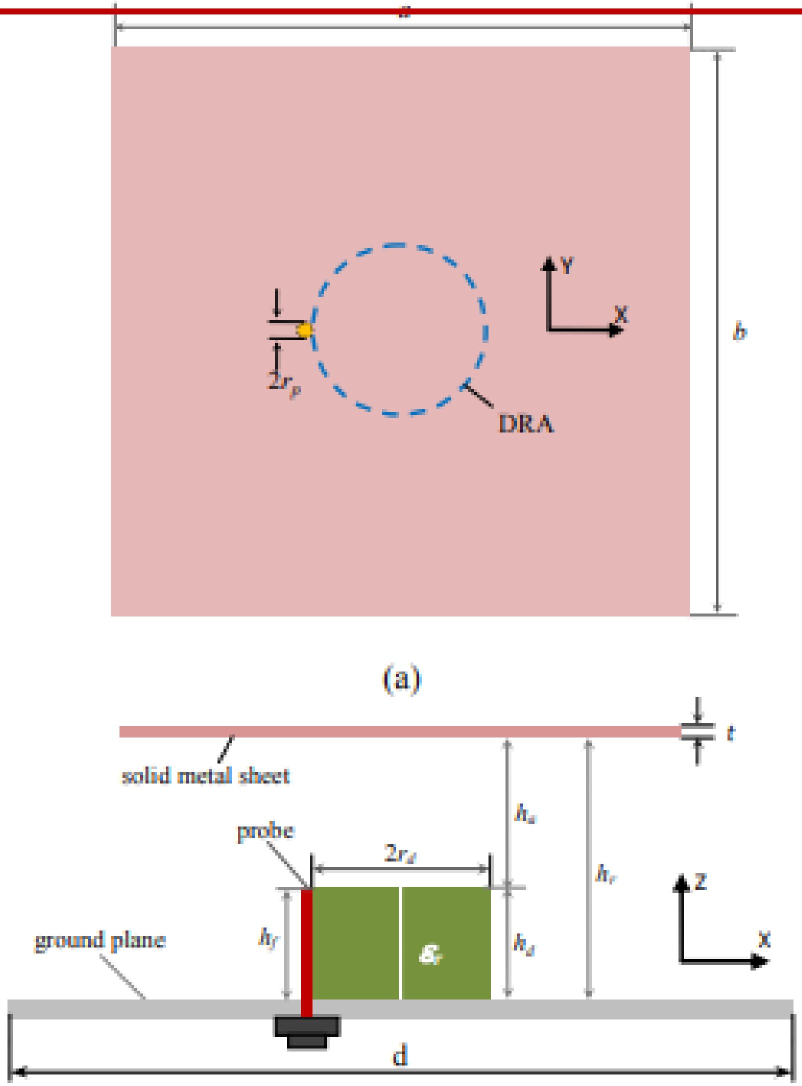
[24]

Performance Improvement Techniques in DRA

Gain Improvement Techniques:

4) Superstrate Loaded DRA:

Metal Superstrate:



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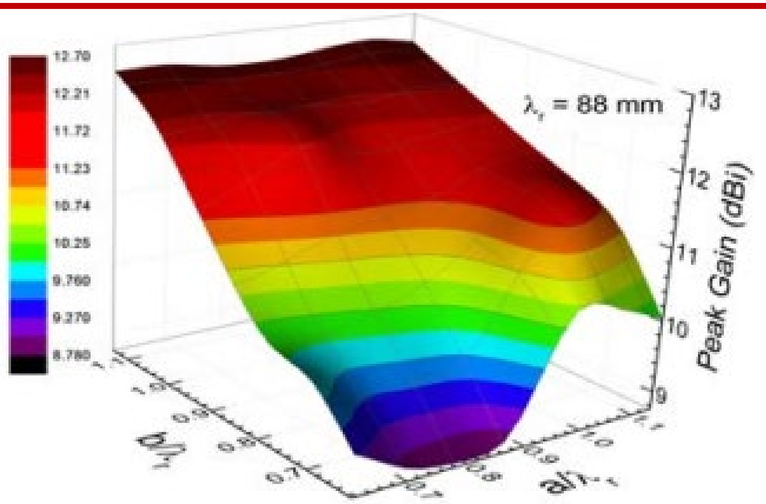
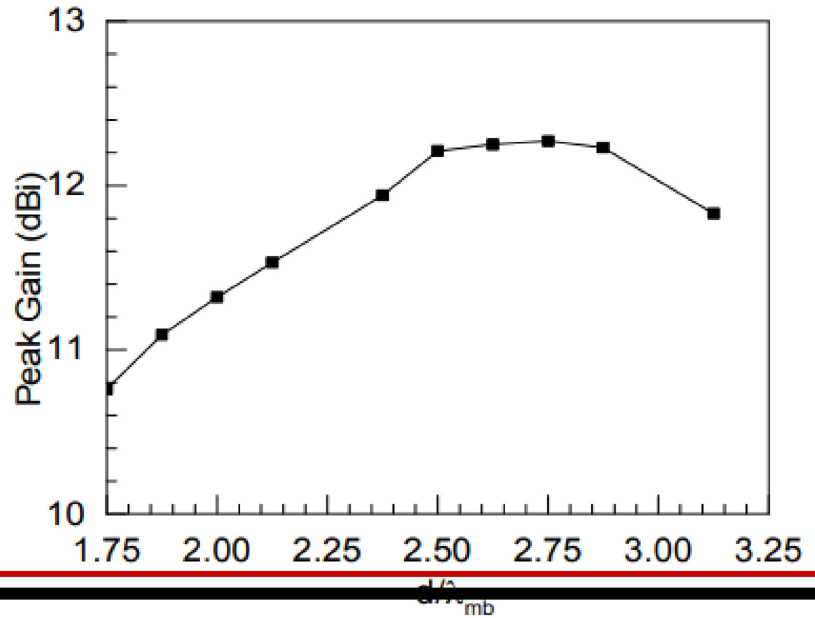


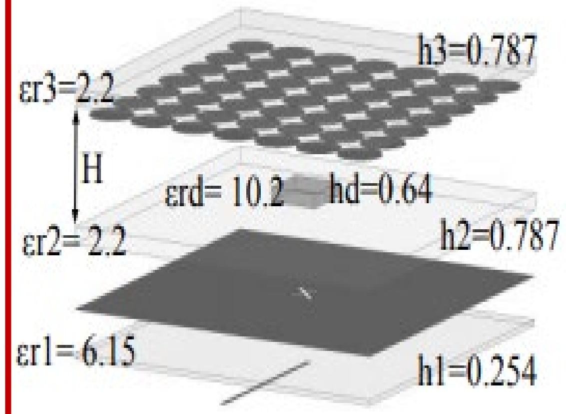


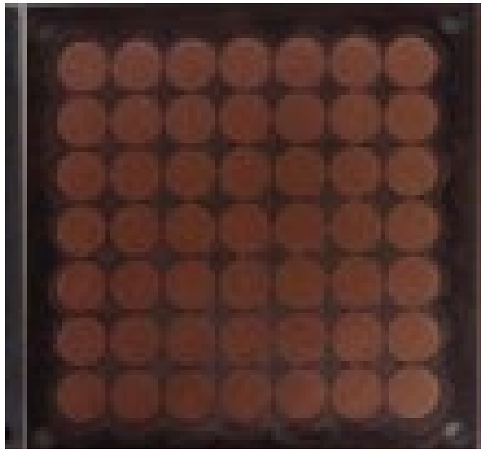
Performance Improvement Techniques in DRA

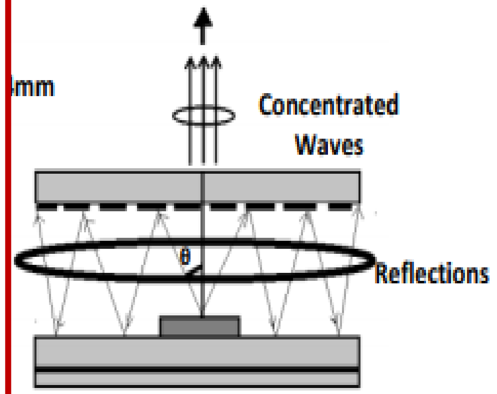
Gain Improvement Techniques:

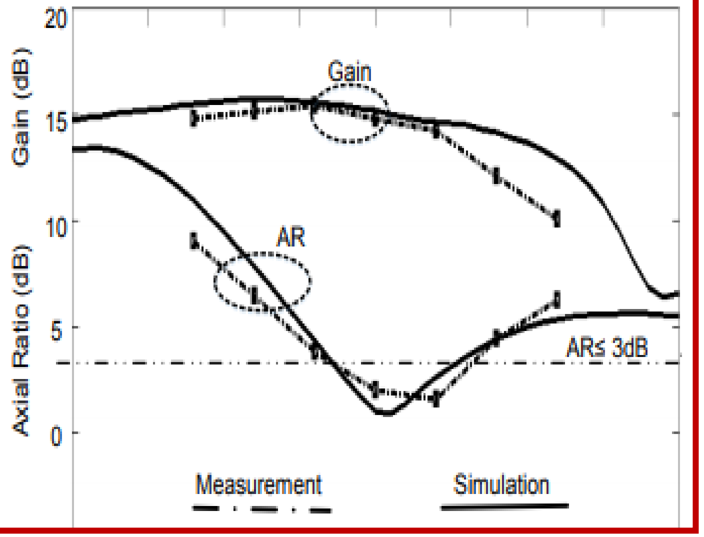
4) Superstrate Loaded DRA:

FSS Superstrate:



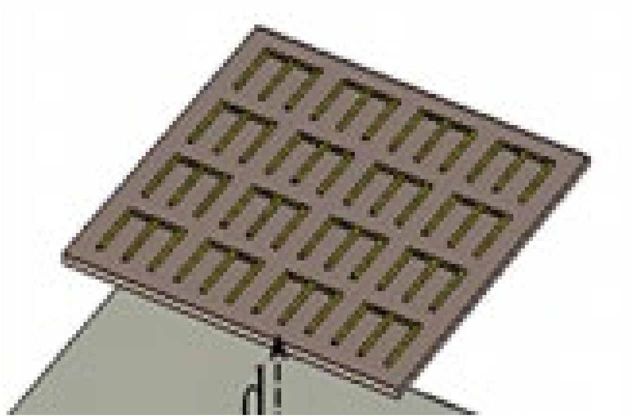


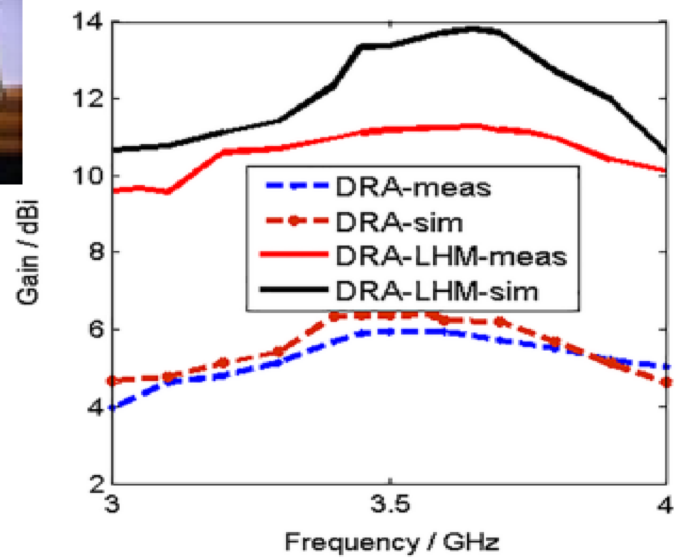




[26]

Metamaterial Superstrate:





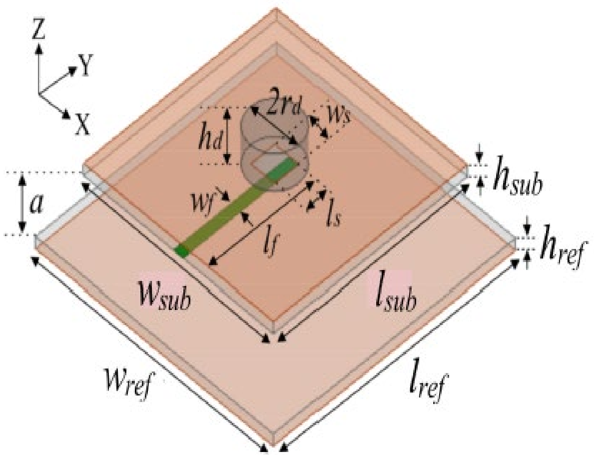
[27]

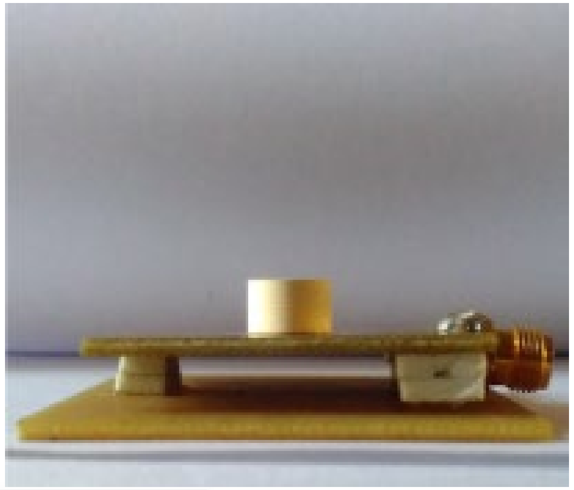
Performance Improvement Techniques in DRA

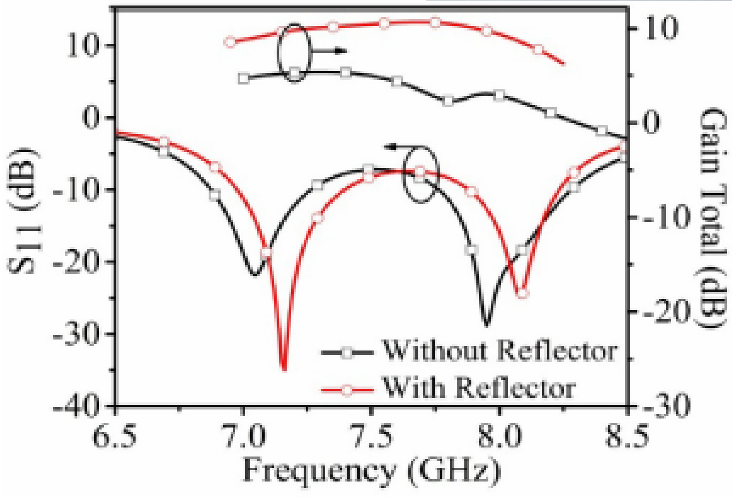
Gain Improvement Techniques:

5) Reflector Backed DRA:

Flat Dielectric Reflector

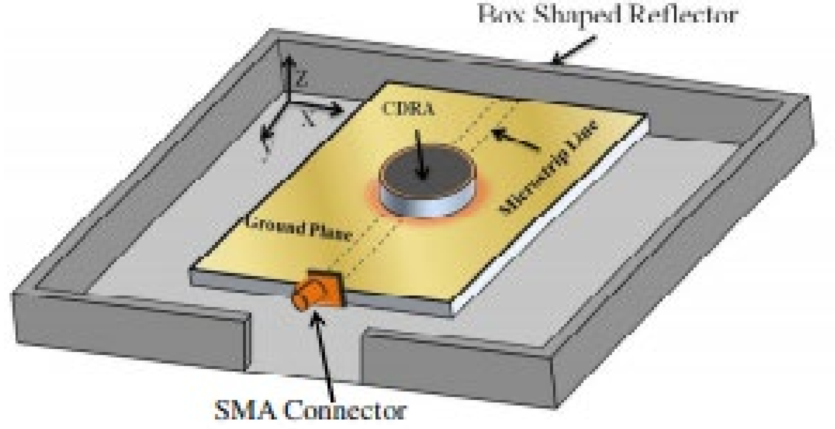


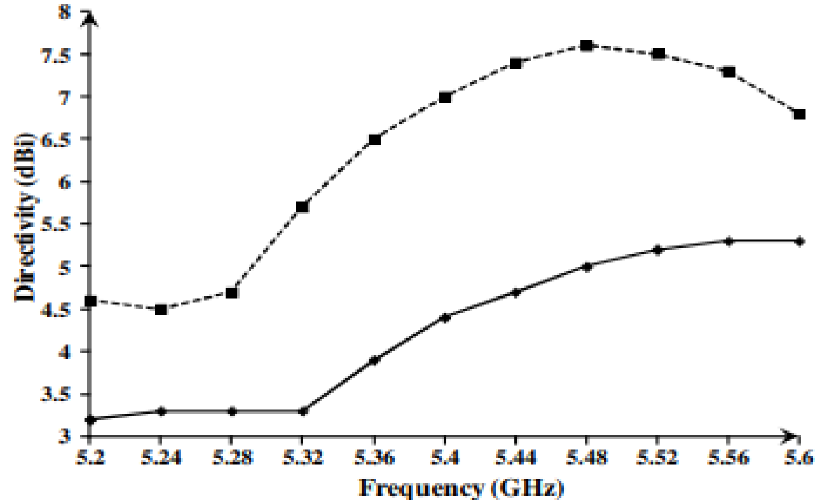




[28]

Metal Box Reflector





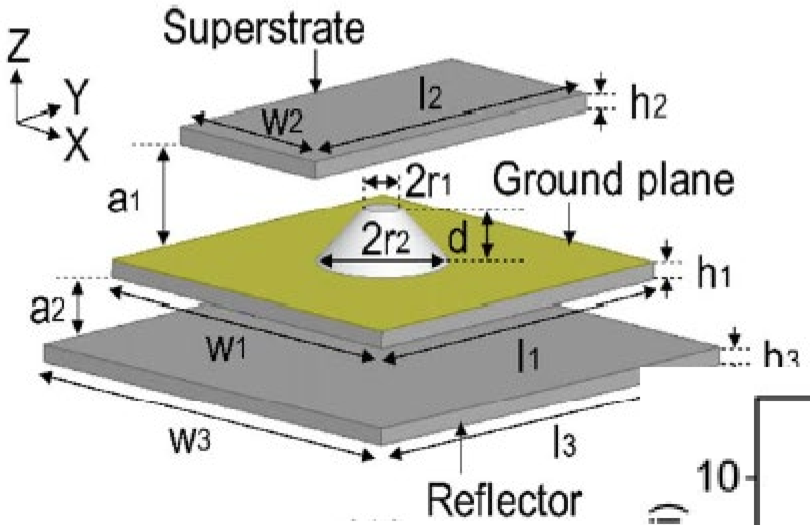
[29]

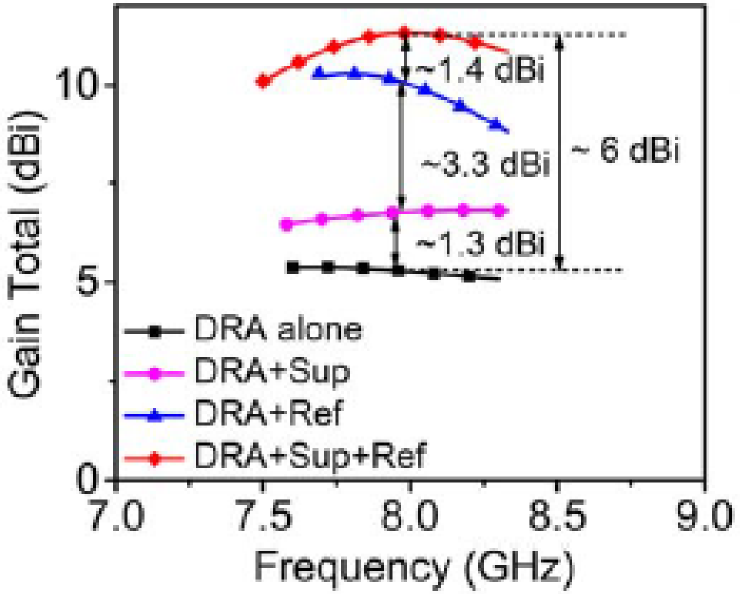
Performance Improvement Techniques in DRA

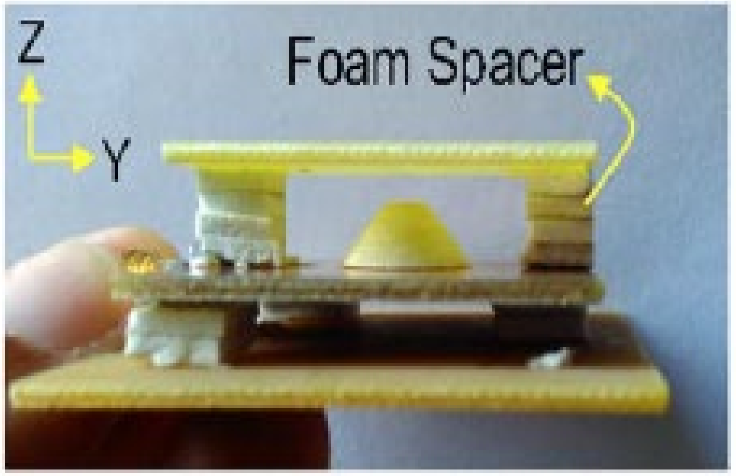
Gain Improvement Techniques:

5) Superstrate and Reflector Backed DRA:

Superstrate + Flat Dielectric Reflector





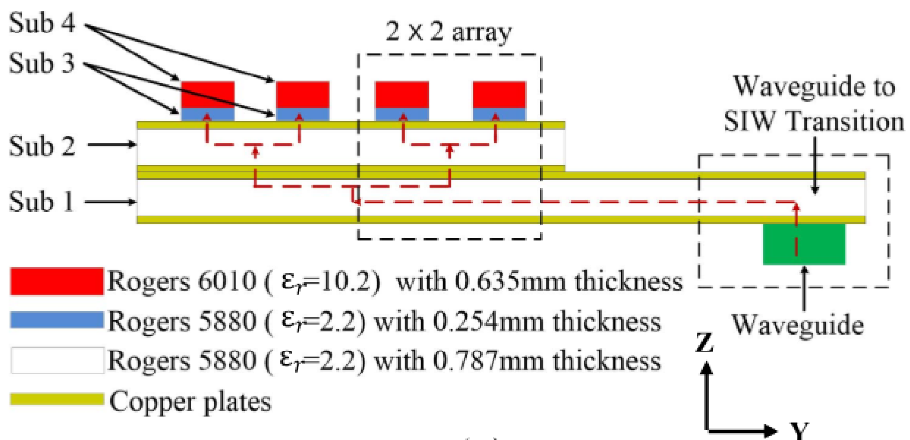


[30]

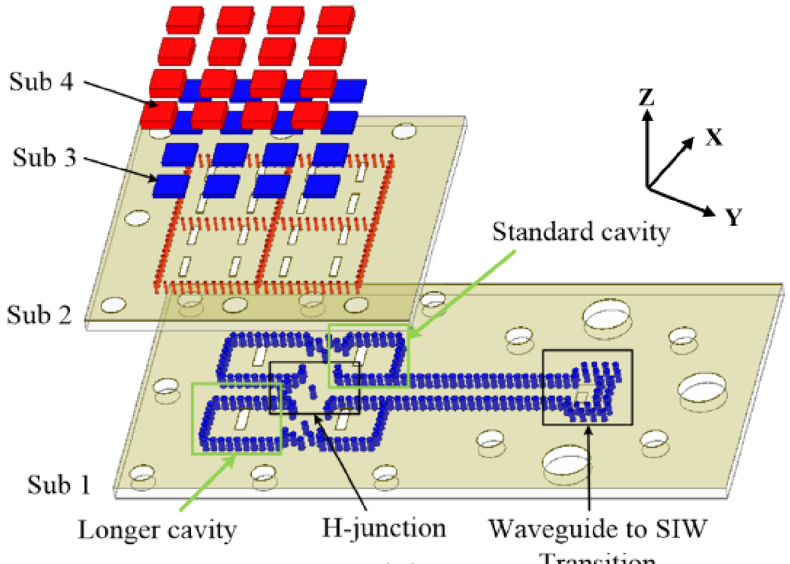
Performance Improvement Techniques in DRA

Gain Improvement Techniques:

6) DRA Array:



(a)



(b)

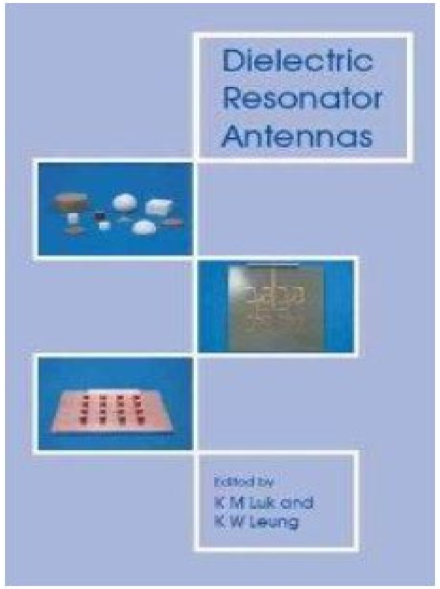
1. **Improved Bandwidth**: The DRA array demonstrates a significant increase in bandwidth, achieving an enhancement of 16.4%.
2. **Enhanced Gain**: The antenna array features an increased gain, reaching up to 17.2 dBi.
3. **Larger Dimensions**: The dimensions of the DRA have been increased, which contributes to the improved performance metrics (bandwidth and gain).

[31]

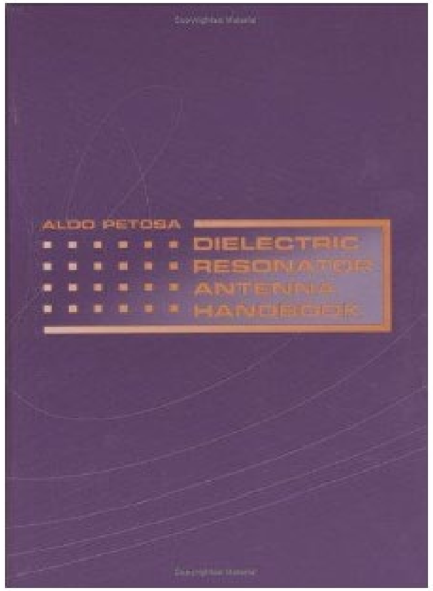
Conclusion

- DRA can be considered as a possible solution for modern wireless communication systems.
- It can be suitably use for microwave and millimetre-wave frequency bands.
- As operating frequencies continue to rise, DRAs will become much more useful (small size by factor of $\sqrt{\varepsilon_r}$, low loss)
- Offer more degrees of freedom for hybrid integration.
- Need to develop integration techniques for fabrication.

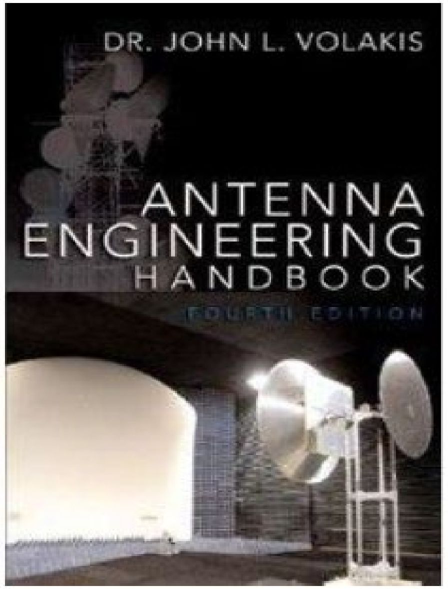
Books on DRA



Dielectric Resonator Antennas
Edited by
K M Luk and
K W Leung



ALDO PETOSA
DIELECTRIC
RESONATOR
ANTENNA
HANDBOOK



DR. JOHN L. VOLAKIS
ANTENNA
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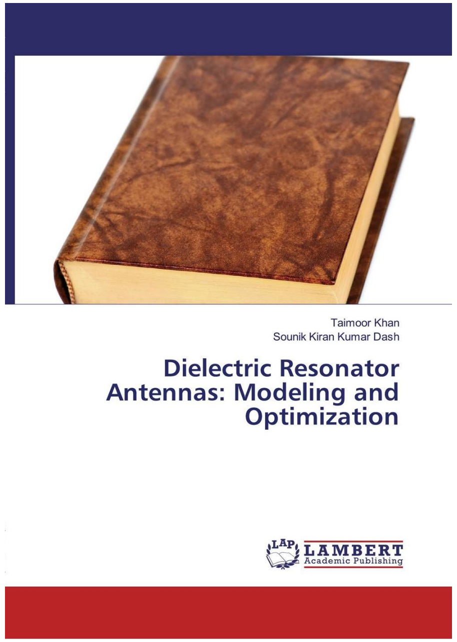
FOURTH EDITION



Taimoor Khan
Sounik Kiran Kumar Dash
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Optimization
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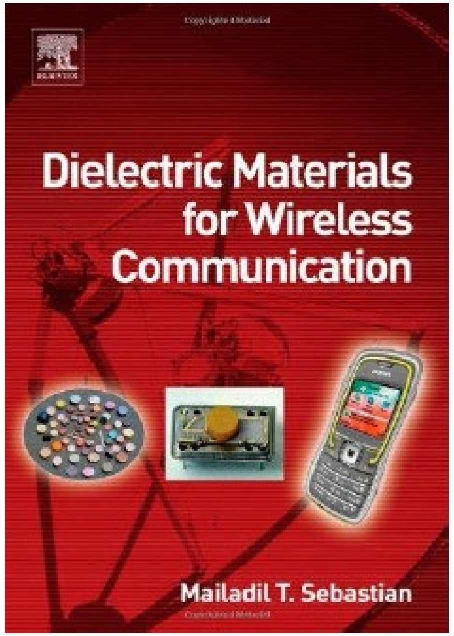
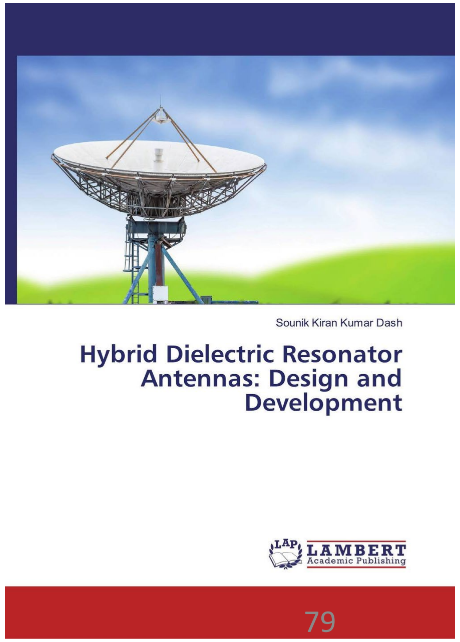


Dielectric Materials
for Wireless
Communication
Mailadil T. Sebastian



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Hybrid Dielectric Resonator
Antennas: Design and
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Thank You

	第10周 春季学期	22 十四	23 十五	24 十六	25 十七	26 十八	27 十九	28 二十
	第11周 春季学期	29 廿一	30 廿二	1 劳动节	2 廿四	3 廿五	4 青年节	5 立夏
5月	第12周 春季学期	6 廿八	7 廿九	8 四月	9 初二	10 初三	11 初四	12 母亲节
	第13周 春季学期	13 初六	14 初七	15 初八	16 初九	17 初十	18 十一	19 十二
	第14周 春季学期	20 小满	21 十四	22 十五	23 十六	24 十七	25 十八	26 十九
	第15周 春季学期	27 二十	28 廿一	29 廿二	30 廿三	31 廿四	1 儿童节	2 廿六
	第16周 春季学期	3 廿七	4 廿八	5 芒种	6 五月	7 初二	8 初三	9 初四

周次	**Lecture**	**Labs**
11	**DRA**	Dual Band Antenna (April 28)
12	**Antenna Optimization Techniques**	Horn Antenna/Measurement/Projects
13	**Emerging Antenna Technologies**	Projects
14	**Progress Report Pre.**	Projects
15	**Wave Propagation**	Projects
16	**Review and Final Project Pre.**	Final Project Pre.

题目：使用MATLAB的DRA工具包分析DRA天线的输入阻抗及带宽特性

圆柱形DRA 【UG】
矩形DRA 【PG】

要求：使用MATLAB的DRA工具包分析矩形介质棒天线（Rectangular Dielectric Resonator Antenna, RDRA）和圆柱形介质棒天线（Cylindrical Dielectric Resonator Antenna, CDRA）；设计两种天线结构，使它们的工作频率为5 GHz；分析输入阻抗随介质介电常数（εr）变化的特性，分别为两种天线结构绘制输入阻抗随εr变化的曲线图；用扫参法绘制两种天线结构的带宽随εr变化的曲线图；提交设计报告，包括天线参数、性能指标及仿真结果的详细描述。

参考答案：首先，打开MATLAB，导入DRA工具包。为了使RDRA和CDRA的工作频率为5 GHz，可以选择合适的尺寸和参数。例如，对于RDRA，可选用εr = 10的介质材料，通过计算和调整尺寸参数，得到长宽高分别为a = 15 mm，b = 15 mm，h = 6.5 mm的矩形介质棒。对于CDRA，同样选用εr = 10的介质材料，可以得到直径d = 15 mm，高度h = 6.5 mm的圆柱形介质棒。使用DRA工具包中的函数计算RDRA和CDRA的输入阻抗随εr变化的特性。例如，使用'dra_input_impedance()'函数计算输入阻抗。遍历不同的εr值（如εr从2到15），分别计算两种天线结构的输入阻抗，并绘制输入阻抗随εr变化的曲线图。用扫参法绘制两种天线结构的带宽随εr变化的曲线图。遍历不同的εr值，分别计算两种天线结构的带宽（例如，定义S11小于-10 dB的频率范围为带宽），并绘制带宽随εr变化的曲线图。设计报告应包括以下内容：天线参数：介质材料、尺寸等；性能指标：输入阻抗、带宽等；仿真结果：输入阻抗随εr变化的曲线图、带宽随εr变化的曲线图。