

A Review on Dielectric Resonator Antenna and Its Analysis Setup

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ABSTRACT

In this article the basic theory about the Dielectric Resonator Antenna (DRA), there different geometries, advantages, disadvantages, applications & characteristics have been discussed. In this article different parameters of DRA and their effects on the performance of DRA are also highlighted. The article explains different type of analysis setups such as Ansoft High Frequency Structure Simulator (HFSS) and CST for analysis of DRA. The article also provides a design manual for designing of DRA in Ansoft HFSS software with a suitable example.

Keywords: HFSS, DRA CST, DRA, MOM, FEM, SDT, SFP/XFP

I. INTRODUCTION

Dielectric Resonator Antenna: 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

frequency millimetre wave applications, where the loss from metallic antennas can be high.

1.3 Disadvantages of DRAs:-

- One of the important disadvantages is proximity of resonant frequencies of various modes. It is therefore of great importance to know the resonant frequency and the field pattern not only for the desired mode of operation (usually) but also for other undesired modes.
- DR antennas are, however inconvenient for the design of a specific resonate frequency compared to microstrip antennas. It is relatively uneasy to form a DR with special configurations and almost impossible to make slight geometrical modifications to a constructed DR, in order to compensate for manufacturing tolerances or fabrication errors.

1.4 Applications of DRAs:-

- Attractive for conformal applications, such as mobile satellite communications.
- The high efficiencies make DRAs suitable candidates for millimeters-wave arrays.
- Mobile phone handsets.[13]
- Laptops.
- PDAs.
- Biomedical Telemetry etc

1.5 DRA Characteristics:-

- It 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.

II. METHODS OF ANALYSIS

The DRA generally has a two-dimensional radiating patch on a thin dielectric substrate and therefore may be categorized as a two-dimensional planar component for analysis purposes. The analysis methods for DRAs can be broadly divided into two groups.

In the first group, the methods are based on equivalent magnetic current distribution around the patch edges (similar to slot antennas). There are three popular analytical techniques:

- The transmission line model;
- The cavity model;
- The MNM.

In the second group, the methods are based on the electric current distribution on the patch conductor and the ground plane (similar to dipole antennas, used in conjunction with full-wave simulation/numerical analysis methods). Some of the numerical methods for analysing MSAs are listed as follows:

- The method of moments (MOM);
- The finite-element method (FEM);
- The spectral domain technique (SDT);
- The finite-difference time domain (FDTD) method.

2.1 HFSS: Ansoft High Frequency Structure Simulator (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. 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.

Typical uses include:

- Package Modelling – BGA, QFP, flip-Chip,

- PCB Board Modelling – Power/Ground planes, Mesh Grid Grounds, Backplanes,
- Silicon/Gas-Spiral Inductors, Transformers,
- EMC/EMI–Shield Enclosures, Coupling, Near- or Far-Field Radiation,
- Antennas/Mobile Communications–Patches, Dipoles, Horns, Conformal Cell Phone Antennas, Quadra
- filar Helix, Specific Absorption Rate(SAR), Infinite Arrays, Radar Cross Section(RCS), Frequency Selective Surfaces(FSS),
- Connectors–Coax, SFP/XFP, Backplane, Transitions,
- Waveguide–Filters, Resonators, Transitions, Couplers,
- Filters–Cavity Filters, Microstrip, Dielectric.

HFSS is an interactive simulation system whose basic mesh element is a tetrahedron. This allows you to solve any arbitrary 3D geometry, especially those with complex curves and shapes, in a fraction of the time it would take using other techniques. The name HFSS stands for High Frequency Structure Simulator. Ansoft pioneered the use of the Finite Element Method (FEM) for EM simulation by developing/implementing technologies such as tangential vector finite elements, adaptive meshing, and Adaptive Lanczos-Pade Sweep (ALPS). Today, HFSS continues to lead the industry with innovations such as Modes-to-Nodes and Full- Wave Spice. Ansoft HFSS has evolved over a period of years with input from many users and industries. In industry, Ansoft HFSS is the tool of choice for high-productivity research, development, and virtual prototyping. This chapter provides an insight into the various aspects involved in the process of setting up and running a simulation in HFSS. The version used is Agilent version 5.6. HFSS is a software package for electromagnetic modelling and analysis of passive, three-dimensional structures. It helps the user to observe and analyze various electromagnetic properties of the structure such as radiation patterns and scattering parameters. While it is not necessary to be an expert in numerical electromagnetic to use HFSS, it is important to understand each step of the

modelling process in details so as to obtain accurate and reliable results. This chapter aims to provide this understanding from a general point of view.

2.2 The Finite Element Method and HFSS: In order to calculate the full three-dimensional electromagnetic field inside a structure and the corresponding S-parameters, HFSS employs the finite element method (FEM). FEM is a very powerful tool for solving complex engineering problems, the mathematical formulation of which is not only challenging but also tedious. The basic approach of this method is to divide a complex structure into smaller sections of finite dimensions known as elements. These elements are connected to each other via joints called nodes. Each unique element is then solved independently of the others thereby drastically reducing the solution complexity. The final solution is then computed by reconnecting all the elements and combining their solutions. These processes are named assembly and solution respectively in the FEM [3]. FEM finds applications not only in electro-magnetic but also in other branches of engineering such as plane stress problems in mechanical engineering, vehicle aerodynamics and heat transfer. FEM is the basis of simulation in HFSS. HFSS divides the geometric model into a large number of tetrahedral elements. Each tetrahedron is composed of four equilateral triangles and the collection of tetra hydra forms what is known as the finite element mesh. At each vertex of the tetrahedron, components of the field tangential to the three edges meeting at that vertex are stored. The other stored component is the vector field at the midpoint of selected edges, which is also tangential to a face and normal to the edge. Using these stored values, the vector field quantity such as the H-field or the E-field inside each tetrahedron is estimated. A first-order tangential element basis function is used for performing the interpolation. Maxwell's equations are then formulated from the field quantities and are later transformed into matrix equations that can be solve do sing traditional numerical techniques.

2.3 Creating Designs Automatically: Ansoft HFSS is the 3-D electromagnetic simulation software package that is chosen to perform simulations of the various

antenna designs. It is a widely used package for antenna modelling and simulations. In order to do the simulation, a 3-D model of the antenna structure called an antenna design project, needs to be built inside the HFSS 3-D Modeller window. The model can be built manually by using the HFSS graphic user interface. However this is a time consuming task, and particularly for intricate geometrical shapes such as fractals, it is extremely difficult and time consuming to manually draw the shapes especially to the required accuracy. The solution to this problem was to generate the 3-D model automatically by using HFSS macros. A HFSS macro is a collection of HFSS commands arranged in the Visual Basic (VB) script format. We can generate a list of HFSS drawing commands with the required accuracy that will form the structure of the antenna. We wrote custom software that we referred to as the HFSS Converter which was developed in the MATLAB programming language. This generated HFSS macros that contained HFSS commands to build intricate and complex geometric structures in HFSS 3-D Modeller. Vertices of the fractal shapes were calculated using MATLAB scripts, and biasing the HFSS Converter, the set of vertices was translated into HFSS commands. Running the macro produces the 3-D structure of the antenna inside HFSS 3-D Modeller. The benefit of using the HFSS Converter was that to simulate the various fractal shapes in HFSS, all that is required to do is to generate the vertices that define the shape itself in MATLAB. As long as the vertices are defined properly, the HFSS Converter would handle the generation of the 3-D model in HFSS. With the HFSS Converter completed, MATLAB scripts were written that generated vertices for a number of different fractal geometries. Using the scripts and the HFSS Converter, a number of microstrip antennas based on Hilbert space-filling curve were simulated in HFSS. Matching performance and gain patterns were characterised. Also two variations of a Log-Periodic design were considered. The Log-Periodic antenna is a broadband antenna design with desirable gain characteristics. The Log-Periodic antenna and the corresponding array were designed and simulated on

the basis of having a more conventional design and for comparison with the fractal constructions.

2.4 Process Overview: The first step is to draw the geometric model of the structure that is to be analysed. The next step is to select the materials that the various drawn objects are made of. An accurate definition of boundaries for the structure, such as, perfect magnetic or electric conductor, follows next. In HFSS, a port or a voltage source needs to be defined to excite the structure. This is done as part of boundary definitions. Once the structure is completely modelled, the solution is set up. This includes definition of various parameters such as the frequency at which the adaptive mesh refinement takes place and the convergence criterion. Finally, after the completion of the simulation, the solution data is post processed which may include display of far-field plots, Smith Chart graphs and tables of S-parameter data.

III. ALGORITHM AND DESIGN MANUAL

3.1 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.

3.2 Design Example for Simulation of DRA in Ansoft HFSS Software:-

1. Open and Save a new project:-

Open new project:-When we will open the software it will automatically open a new project window, just rename as per our requirement (RDRA). It will open the new window which looks like this.

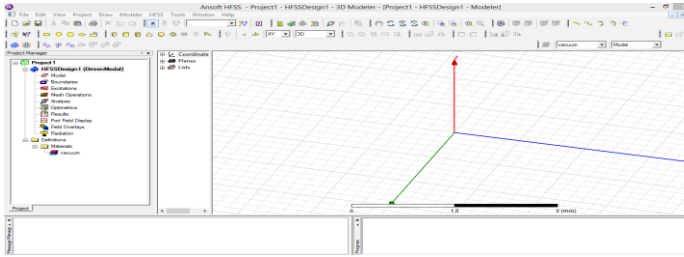


Fig 3.1 HFSS Window

Elements of HFSS Window:-

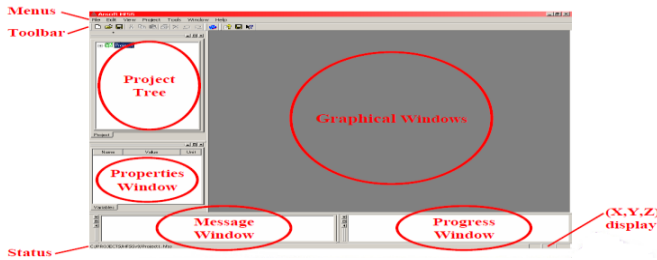


Fig 3.2 Elements of HFSS

Save the project:-

Go to file click on 'save as' it will save the project where ever we want depend upon our requirement.

2. Set the drawing unit before we start design

Go to modeler in menu and click on units it will one unit window select our required unit normally we select 'mm'

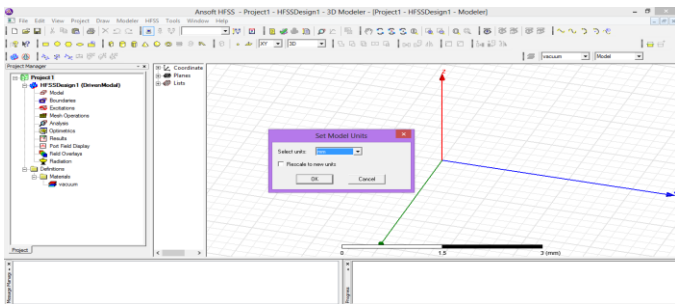


Fig 3.3 Unit Window

3. Drawing Different Units

Take ground plane: For taking ground plane select Draw Box from the toolbar, if it is not available in toolbar than bring cursor to toolbar and by right click on mouse at anywhere in toolbar it will give us list in that click tick on 3D Draw solid. Or go to menu in that click on draw and then click box. Our aim is draw 50x50x3 ground plane. We want it should look in center. Ground plane of 50x50x3

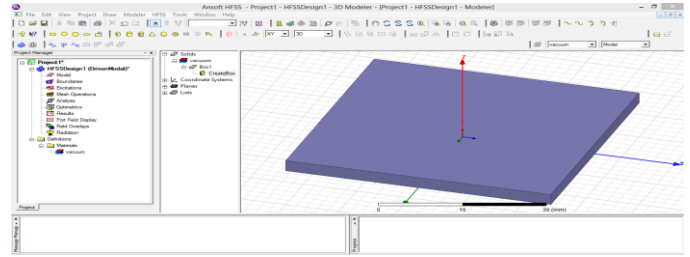


Fig 3.4 Ground Plane

Change the name of box. For that go to history tree in that double click on box1 and change the name as ground. Change the dimension of box as 50x50x3. For that go to the history tree and expand ground in that double click on create box. Now we will get one small window in that change position, x size, y size and z size as shown in below. Assign the material for ground. For assigning the material right click on grounded select 'pec' material.

Draw rectangular DRA: Do same as ground for rename and dimensions. Draw rectangular DRA with dimension of 10x10x10(Length x Width x Height). Do same as ground for rename and dimensions. Assign material for RADAR. For that repeat same but select RADAR from history tree and select add new material (dielectric constant is 20).

Designing of Coaxial probe for feeding Rectangular DRA: For designing of coaxial feed first we will calculate coaxial parameter. Inner Diameter-D1, Outer Diameter-D2, Dielectric material- Teflon, Conductor material- PEC

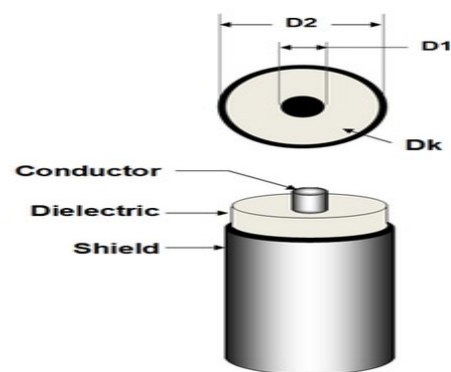


Fig 3.5 Coaxial Cable

Calculation of Coaxial Probe parameter: Go to the below link and enter the data as impedance 50 Ω and dielectric material constant 2.1(Teflon). http://www1.sphere.ne.jp/i-lab/ilab/tool/cx_line_e.htm

Designing of dielectric part for coaxial probe: Select cylinder dimension of 2 mm radius with 3 mm heightened subtract with ground which will create hole of taken cylinder , now again take same dimension cylinder.

How to do subtraction from one shape to other shape: Select both shape from the history tree and perform subtract operation.

Designing of conductor part for coaxial probe: Select one cylinder of 0.6 mm radius and 7 mm height and subtract from dielectric part which will create hole of required dimension. Now again select a cylinder of the same dimensions.

4. Designing of Radiation and Excitation:

Designing of radiation box: Take one box dimension of 50 mm x 50 mm x 50 mm which will a vacuum.

Assign the box as radiation box.

Assigning of port for excitation of coaxial probe: Take one circle to cover the coaxial feed point so that we can assign the port. Assign wave port as excitation, select circle form history tree and right click on that select assign excitation in that again select Wave port. Now we need to define integration line as new line manually we need to define the line from center to circumference. After define integration line, it will be defined which is showing in below figure. It will give the impedance of 50 Ω.

Wave port will looks like that after assigning.

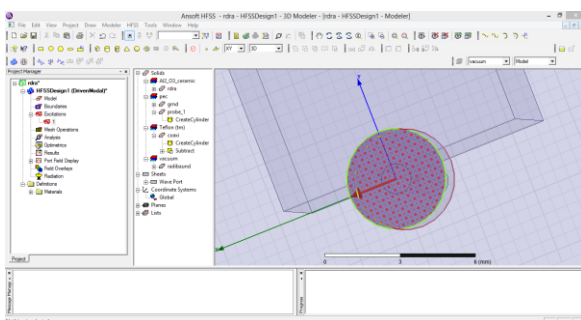


Fig 3.6 Assigning Wave Port

5. Analysis setup:

Go to HFSS and click on that and select analysis setup in that click on add solution setup. After clicking on add solution setup we will get above window in that we need to specify following:-

Maximum number of passes- 5 to 20(depends upon how much fine result we want) Maximum delta S- 0.02

6. Add frequency sweep: Go to HFSS and click on that and select analysis setup in that click on add frequency sweep. After getting the above window we need to do following changes depends upon our requirement:-

Sweep name – sweep

Sweep type- fast

Type – linear count

7. Validation check: Click on validate.

8. Analysis of structure: Click on analysis all.

9. Results: Go to HFSS and click on results tab.

S11 versus frequency curve: It will show the return loss versus frequency curve.

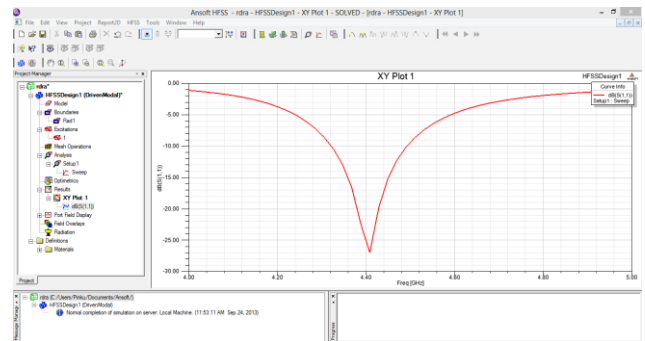


Fig 3.7 Return Loss

Calculation of Resonant frequency and Bandwidth:-

Bandwidth=(m2-m1) Hz

Resonant frequency=m3 Hz

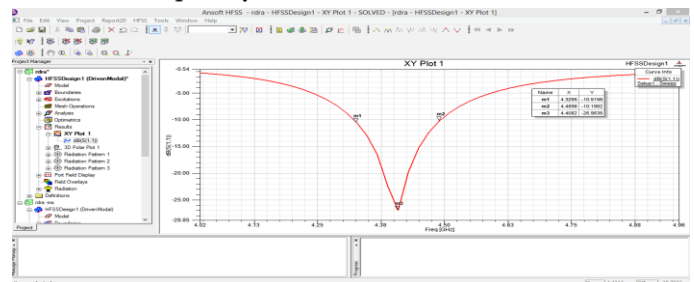


Fig 3.8 Calculation of Resonant frequency and Bandwidth

3-D radiation pattern:- For getting the 3-D radiation pattern, goto HFSS then select results then select create far field report than select 3-D polar plot.

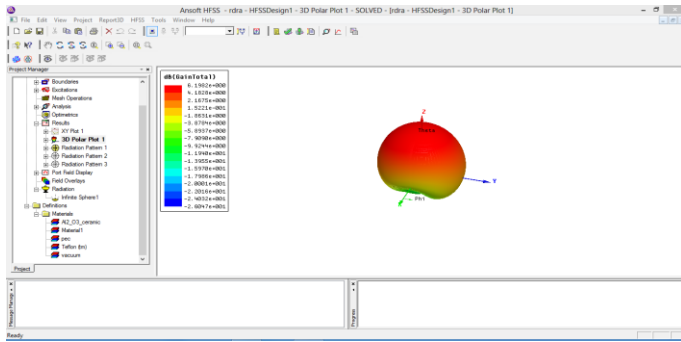


Fig. 6.9 3-D Radiation Pattern

IV. CONCLUSION

Thus the article explains the basic theory and system design for Dielectric Resonator Antenna. 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.

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