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Comparative Studies of Rectangular Dielectric Resonator Antenna with Probe and Microstrip line Feeds

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Abstract

In this paper, the design of rectangular dielectric resonator antenna (RDRA) with coaxial probe and microstrip line feed arrangements and corresponding return loss vs. frequency characteristics and radiation performance in C-band of microwave frequencies using finite integration method (CST Microwave Studio) and verified by finite element method (Ansoft High Frequency Structure Simulator) are presented . The simulation results obtained using the two numerical methods for the probe- and microstrip line-fed RDRA are compared on the basis of feed arrangements and the type of numerical method used. The results of present work may provide design guidelines for the development of efficient RDRA using coaxial probe and microstrip line as feeds.

Keywords: CST Microwave Studio, HFSS, Dielectric resonator antenna, probe coupling and microstrip line coupling.

INTRODUCTION

The dielectric resonator (DR) is fabricated from low-loss dielectric material ($\tan\delta \approx 10^{-4}$, or less) and high relative permittivity ($\varepsilon_r \approx 10-100$). Its resonant frequencies are predominantly a function of size, shape, and material permittivity. DRs offer the advantages of small size, lightweight, low profile, and low cost. When a dielectric resonator is not entirely enclosed by a conducting boundary, it can radiate, and so it becomes an antenna, named Dielectric resonator antenna (DRA). DRAs have several merits including high radiation efficiency, flexible feed arrangement, simple geometry, and compactness [1]-[4]. As compared to microstrip antenna, DRAs have much wider impedance bandwidth and they don't support surface waves. The resonance mode used for radiation depends on the geometry of the resonator and the required radiation pattern. The fields of the mode should not be strongly confined within the resonator and therefore, it can be easily fed to produce high efficiency radiation [5]. Various DRA modes can be excited using different excitation techniques, for example the conducting probe, microstrip line, microstrip slot, co-planar waveguide etc. DRAs are available in various basic classical shapes such as rectangular, cylindrical, spherical and hemispherical geometries. Rectangular DRAs can be designed with greater flexibility since two of the three of its dimensions can be varied independently for a fixed resonant frequency and known dielectric constant of the material [6].The field simulation studies for many DRA configurations using commercially available softwares are reported in the literature [3, 6] in order to obtain optimal design parameters for the antenna

It is proposed to design the RDRA with probe and microstrip line feed arrangements at 5.5 GHz and compare their return loss and input impedance characteristics versus frequency as well as near field distribution and far field pattern at 5.5 GHz through simulation studies using finite integration method (CST Microwave Studio) and finite element method (Ansoft HFSS).

Theory

Dielectric waveguide model [2] has been used to design a rectangular dielectric resonator antenna (RDRA) at 5.5 GHz. The initial dimensions of the radiating portions of the antenna are determined using the equations developed for the dielectric waveguide model (DWM) for a rectangular resonator in free space .Enforcing the magnetic wall boundary condition at the surfaces of the resonator, the following equations are obtained for the wave numbers and the resonance frequency for dominant mode (TE to Z mode):

$$k_x^2 + k_y^2 + k_z^2 = \in_r k_0^2 \tag{1}$$

$$f_0 = \frac{c}{2\pi\sqrt{\in_r}}\sqrt{k_x^2 + k_y^2 + k_z^2} \tag{2}$$

and

$$k_z \tan(\frac{k_z d}{2}) = \sqrt{(\varepsilon_r - 1)k_0^2 - k_z^2} \tag{3}$$

where $k_x (= \frac{\pi}{a})$, $k_y (= \frac{\pi}{b})$, and k_z denote the wave-numbers along the *x*, *y*, and *z* directions within the RDRA structure respectively, and a and b are the broad and narrow cross- sectional dimensions of the RDRA respectively. The dimensions of the antenna parameters are optimized using trial and error technique. The dimensions of RDRA estimated through DWM theory are $10.5 \times 6.0 \times 9.6 mm^3$ at 5.5 GHz.

Field Excitation Techniques

For most practical applications, power is coupled into or out of the RDRA through one or more ports. The selection of a feed and that of its location both determine the number of modes excited within the RDRA and the amount of power coupled from the feed to antenna in each mode. This, in turn, determines the input impedance, its frequency response, and radiation characteristics of the RDRA. In general, to achieve strong coupling, the RDRA must be fabricated from high permittivity materials. Previous work has shown that critical coupling is possible for RDRAs having a high value (20 or more) of dielectric constant [2]. The rectangular DRA can be excited using a variety of techniques including coaxial probes and microstrip lines. In the present study the coaxial probe and direct microstrip line excitation techniques for the RDRA have been examined in C-band of microwave frequencies.

A Probe Coupling

For coupling purposes, the probe can be considered as a vertical electric current source and it should be located in a region of the maximum electric field for the mode to be excited in the RDRA. This can provide strong coupling between the coaxial probe and RDRA. The probe can either be located adjacent to the RDRA or can be embedded within it. The coupling between the probe and RDRA can be controlled by varying the length and the position of probe. The location of the probe also changes the modes which can be excited. Further, it is found that to excite DRAs having value of material permittivity ε_r = 20, shorter probe lengths are required [2], [11]. For DRAs fabricated out of material with ε_r = 20, the length of the probe is approximately equal to the height of the resonator. One advantage of probe excitation is the direct coupling into a 50 Ω system without the need for a matching network. Probes are useful at relatively lower frequencies [9]-[10].

B Microstrip line Coupling

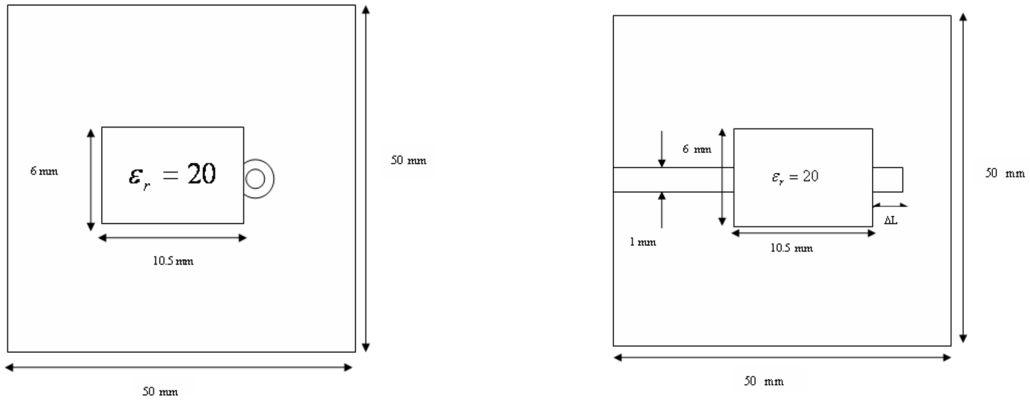
Excitation of RDRA can be done through proximity coupling using microstrip lines. Microstrip coupling excites the magnetic field in the DRA to produce the short horizontal magnetic dipole. The coupling between a microstrip line and DRA is capacitive since the DRA is located near the maximum electric field in the microstrip line. In the microstrip scheme of excitation, the level of coupling can be controlled by varying the lateral distance between the RDRA and the microstrip line and/or the dielectric constant of the DRA material [2]. It has also been found that the coupling decreases with a decrease in the height of the substrate. For values of $\varepsilon_r \geq 20$ strong coupling is achieved; however, the maximum amount of coupling is significantly reduced if the dielectric constant of the RDRA is lowered. This can become problematic if low dielectric constant values are required for obtaining wideband operation [8]-[9].

Antenna Structure Design

The top views of the geometry of RDRA with coaxial probe and microstrip line feeds are shown in Fig. 1 (a) and (b) respectively. The RDRA in each case consists of a dielectric resonator antenna having dimensions $10.5 \times 6.0 \times 9.6 mm^3$ and material dielectric constant ε_r = 20 located on a $50 \times 50 mm^2$ ground plane acting as support for the antenna as well.

The probe fed RDRA is excited by a coaxial probe of length 'L' and diameter 'g' (= 1.3 mm) which is kept at a distance 's' from the antenna. As the coupling to RDRA can be adjusted by varying the length and position of the probe, extensive simulations are carried out using the Microwave Studio and HFSS softwares in order to obtain optimal probe length 'L' and spacing 's' for the proposed antenna .The variations in return loss with frequency for different probe lengths using the microwave studio and HFSS softwares are respectively shown in Figs. 2 and 3. The plot for return loss versus frequency for different positions of the probe using Microwave Studio and HFSS softwares is shown in Fig. 4. From these graphs it can be seen that the maximum coupling and greatest bandwidth are obtained when the length of the probe (L) is 8 mm and the probe is displaced 5.9 mm (=s) from the center along the x-axis.

Microstrip line fed RDRA is excited by 1 mm wide microstrip line on a 0.33 mm thick substrate with a relative dielectric constant ε_r = 2.2 to give characteristic impedance of 50 Ω (Fig.1 (b).The open circuit microstrip line has been considered to excite the RDRA. To achieve the maximum coupling, the RDRA is placed at a distance of λ/2 (27.27 mm at 5.5 GHz) from the open end [2].For this case the maximum coupling and the widest bandwidth are achieved for strip length ΔL = 4.1 mm [3] (Fig.1 (b)).



(a) (b)

Fig. 1 Geometry of proposed antennas (Top View) (a) Probe-fed RDRA (b) Microstrip line-Fed RDRA

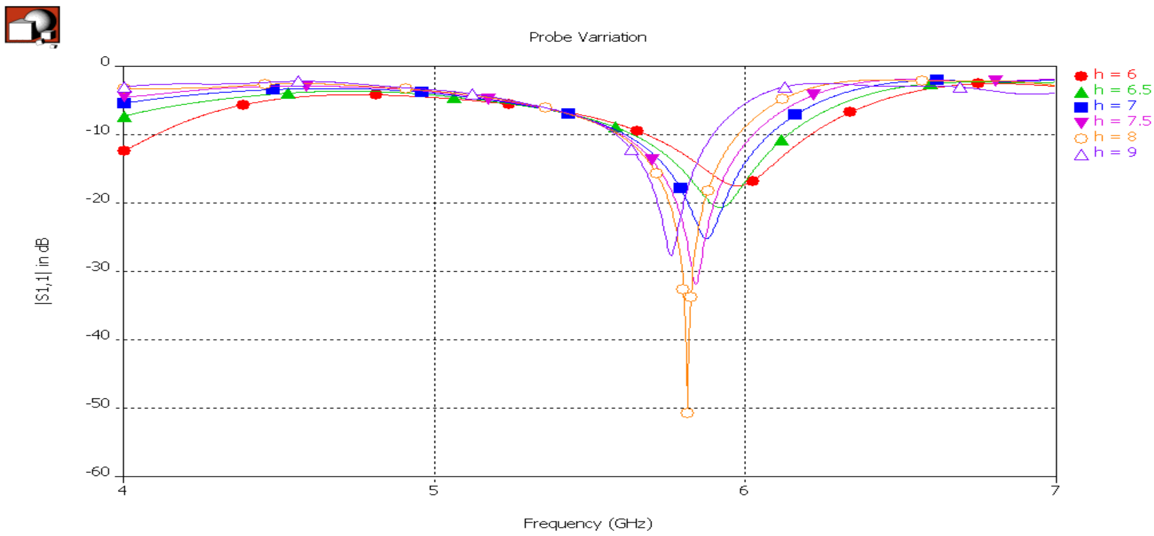


Fig.2. Optimization of probe length for probe-fed RDRA using CST Microwave Studio software

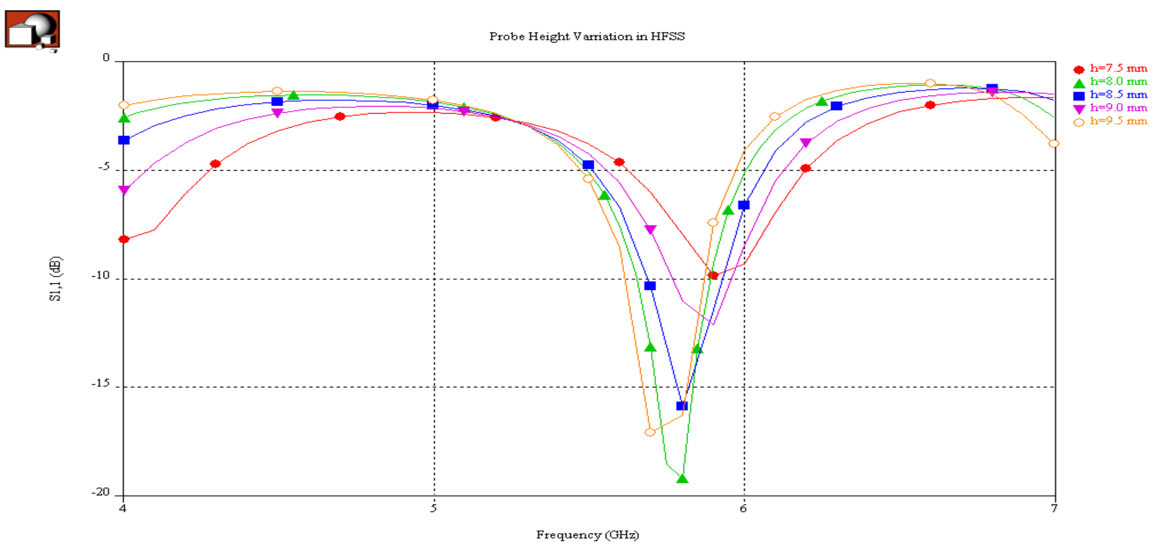


Fig.3. Optimization of probe length for probe-fed RDRA using Ansoft HFSS software

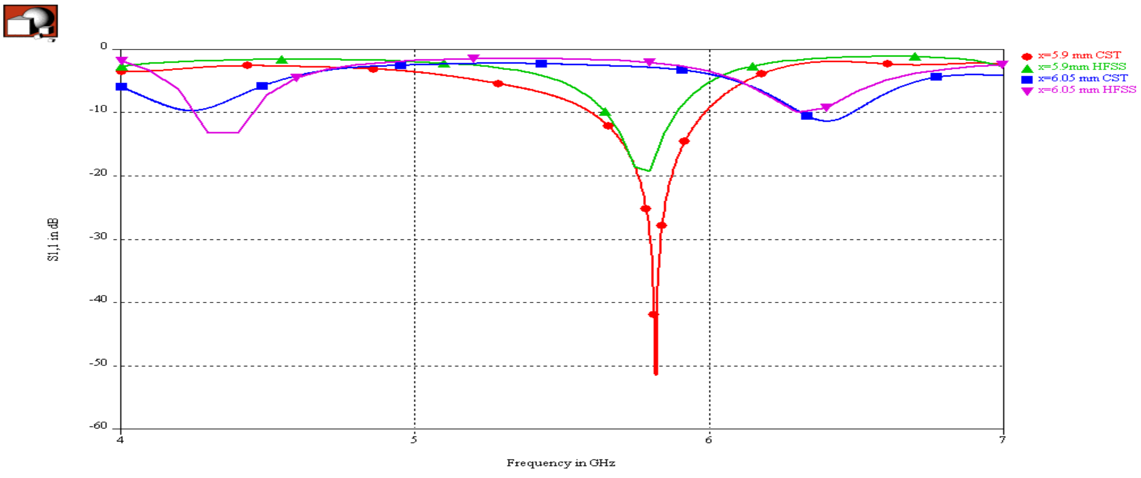


Fig. 4. Optimization of probe position from the centre in the x-direction for probe-fed RDRA using CST Microwave Studio and Ansoft HFSS softwares

RESULT AND DISCUSSION

A Return loss vs. frequency characteristics

Fig.5 shows the simulation results for return loss characteristics of probe and microstrip line-fed RDRA vs. frequency characteristics using finite integration method (CST Microwave Studio) and finite element method (Ansoft High Frequency Structure Simulator). Lowest value of return loss represents the maximum coupling from coupling mechanism to the RDRA. Resonance frequency, 10dB operating frequency range and percentage return loss bandwidth of the RDRA are extracted from Fig. 7 and are given in Table 1. It can be seen from Fig.5 and/or Table 1 that there is similarity between the results obtained using the two softwares for both the feed arrangements, though return loss values using CST Microwave Studio software are higher as compared to those obtained using HFSS software near the resonance frequency. Also, the amount of coupling is greater in probe-coupled RDRA as compared to that in microstrip-line fed RDRA. The resonance frequencies obtained from the both softwares for each of coupling mechanisms are also nearly in agreement with each other. Results also show that the microstrip line coupling mechanism provides wider bandwidth in comparison to probe coupling mechanism. The operating frequency range is wider for the probe coupled RDRA as compared to that for microstrip-line fed RDRA.

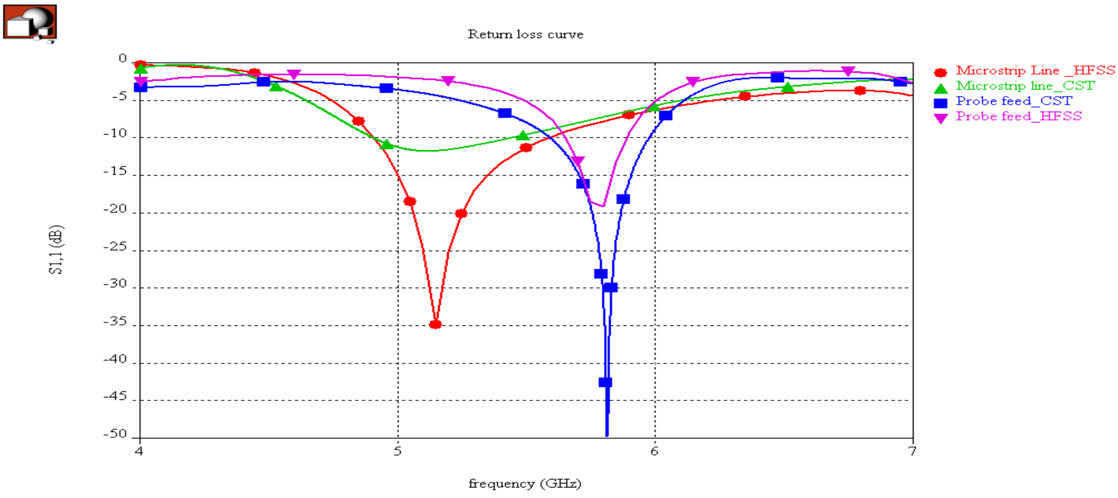


Fig. 5. Return Loss Curve for Probe- and Microstrip line-fed RDRA

Table 1 Comparative Simulation Result for Probe- and Microstrip line-fed RDRA

Parameters	Microstrip Line-Fed RDRA		Probe-Fed RDRA	
	CST Result	HFSS Result	CST Result	HFSS Result
Resonance frequency in GHz	5.116	5.16	5.815	5.81
Operating frequency Range ($\|S_{11}\| = 10dB$)	4.9133 - 5.4368 GHz	4.91 - 5.60 GHz	5.5984 - 5.9742 GHz	5.65 - 5.89 GHz
Return loss Bandwidth in%	10.23	13.37	6.46	4.13

B Input Impedance

The input impedance are shown in Figs.6 and 7 respectively. As can be observed from the Figs.6 and 7 that the resonance frequency corresponds to the point where the imaginary part of the input impedance is zero and the real part is a maximum.

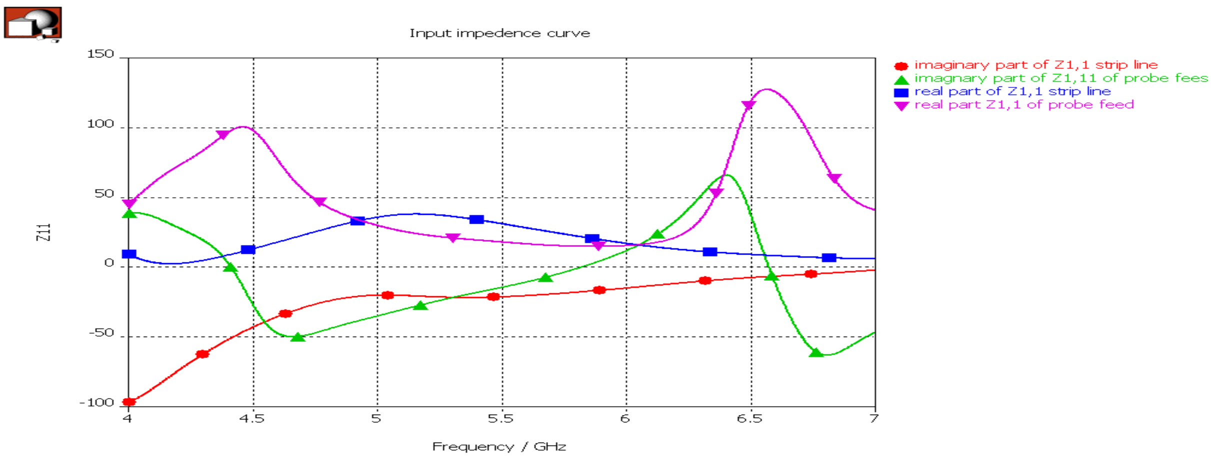


Fig. 6. Input Impedance Curve of RDRA using CST Microwave Studio

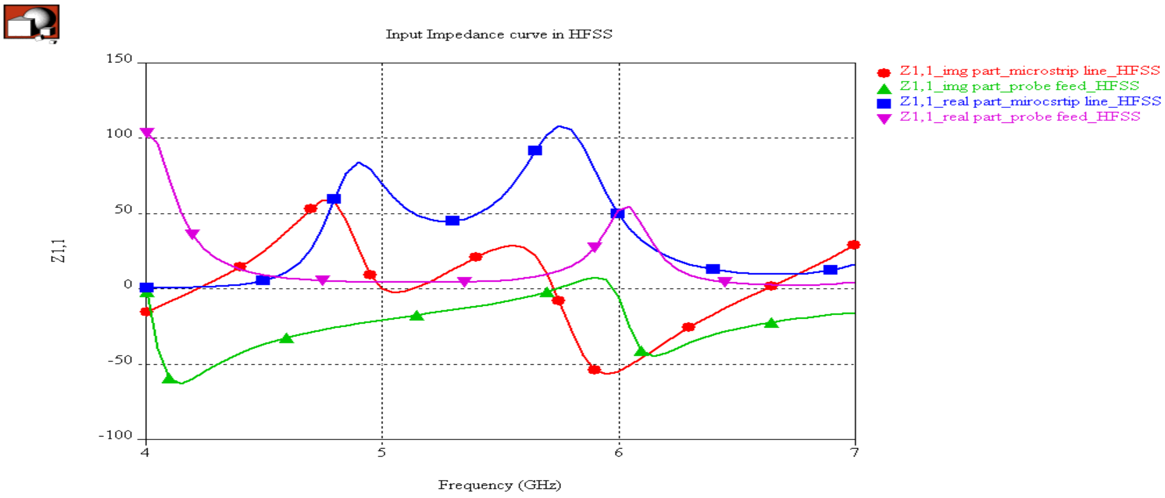
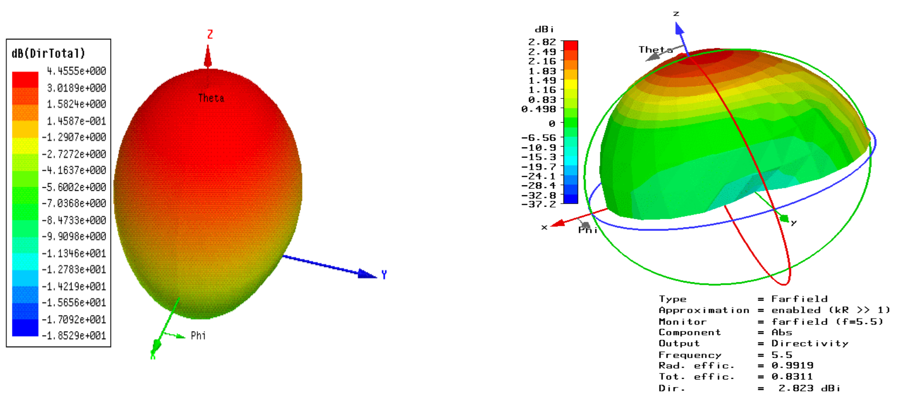


Fig. 7 Input Impedance Curve of RDRA using Ansoft HFSS

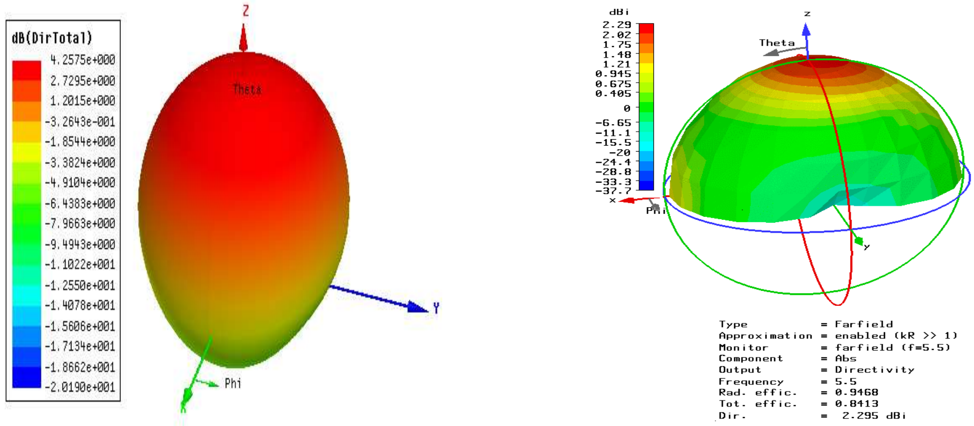
C Far Field Simulation

Figs. 8, 9 and 10 show the simulated radiation patterns of the RDRA for the two coupling mechanisms at 5.5 GHz using finite integration method (CST Microwave Studio) and finite element method (Ansoft High Frequency Structure Simulator) are presented. The radiation parameters of RDRA are extracted from these figures and are given in Table 2. From Figs. 8, 9 and 10 and Table 2, we can observe that the probe-fed RDRA provides higher gain, better directivity, higher radiation efficiency and lower 3-dB beam width as compared with microstrip line-fed RDRA. When compared with CST Microwave Studio software the HFSS software, which is based on finite element modeling provides improved values for most of the radiation parameters excepting total efficiency .The total efficiency for probe fed RDRA using HFSS is lower than that obtained using CST Microwave Studio software.



(a) (b)

Fig .8 3D Far Field Pattern of Probe-fed RDRA from (a) Ansoft HFSS Software (b) CST Microwave Studio Software



(a) (b)

Fig .9 3D Far Field Pattern of microtsrip line fed RDRA from (a) Ansoft HFSS Software (b) CST Microwave Studio Software

Validation of the Analysis

Return loss curve of unit segment and two segment dielectric resonator antennas are computed here with the help of CST Microwave studio have been compared with that computed by P. Rezaei et all [3]. These results are in very good agreement with each other as shown in Fig. 11.

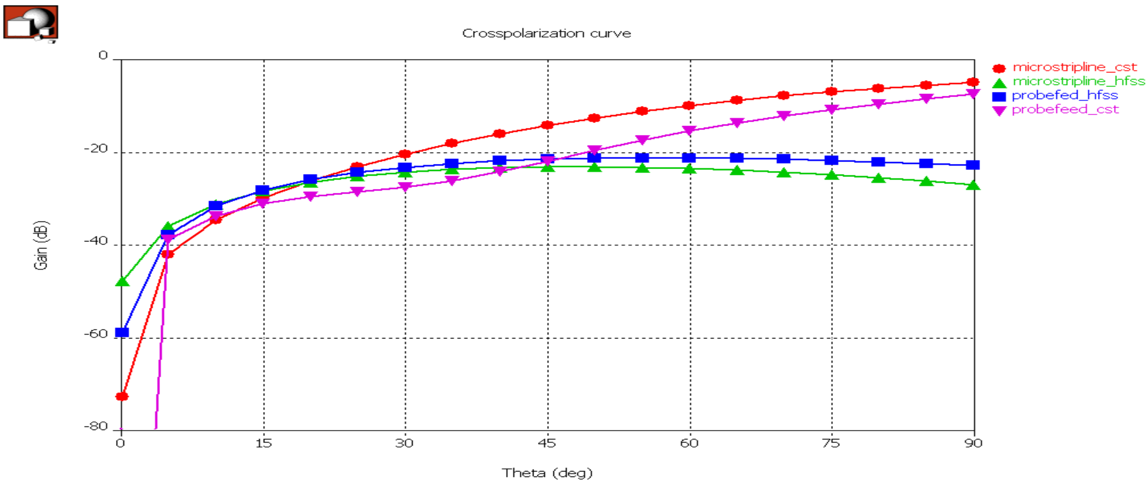


Fig. 10 Cross-polarization Curve for Both coupled RDRA

Table 2 Comparative Simulated Result of RDRA for Probe and Microstrip Line Feeds

Far Field Parameters	Probe-Fed RDRA		Microstrip Line-Fed RDRA	
	CST Result	HFSS Result	CST Result	HFSS Result
Directivity in dBi	2.823	4.4555	2.295	4.2575
Gain in dB	2.788	3.2117	2.058	2.4612
Radiation efficiency in %	99.19	99.42	94.68	99.77
Total efficiency in %	83.11	68.88	84.13	92.52
3-dB Beam-width in deg.	94.2	84	93.1	92.4
Cross Polarization level in dB	-4.973	-21.10	-4.87195	-23.00

CONCLUSION

The analysis of RDRA using probe and microstrip line feed arrangements has been carried out for return loss and input impedance characteristics as a function of frequency in C-band as well as far-field pattern at 5.5 GHz using finite integration method (CST Microwave Studio) and verified by finite element method (Ansoft High Frequency Structure Simulator) are presented. The radiation characteristics of the RDRA obtained using finite element method are found to be better than those obtained using results obtained using finite integration method in most of the cases. The probe-fed RDRA provides better performance in terms of majority of the radiation parameters as compared with microstrip line-fed RDRA. This is in conformity with the finding of Mongia et al [2] who obtained similar results at lower frequencies.

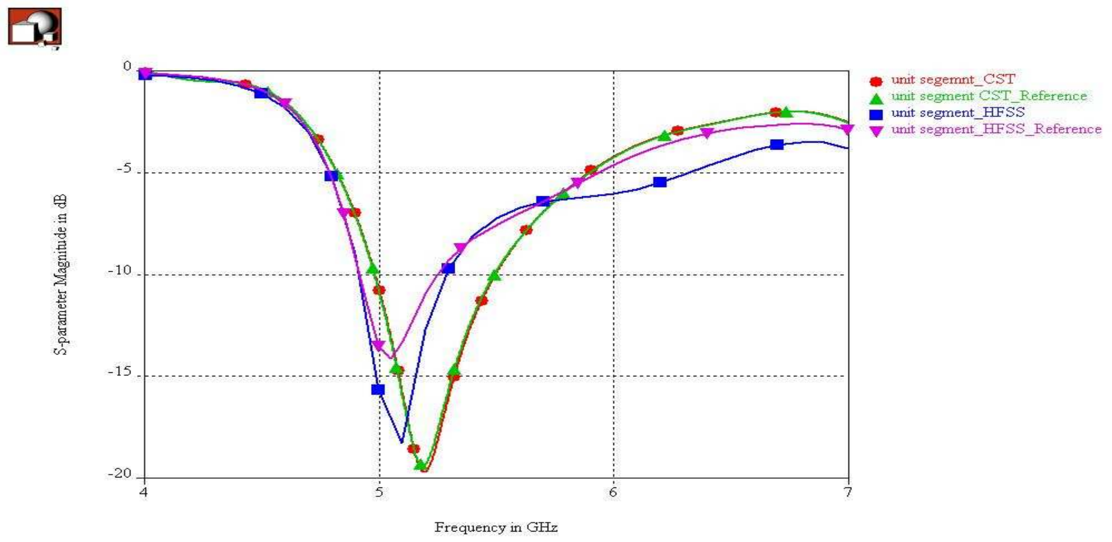


Fig. 11 Return loss curves of unit segment and two segment dielectric resonator antennas are obtained by present method and reference [3].

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