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Design and Analysis of Capacitive and Inductive Fed Rectangular Dielectric Resonator Antenna

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Abstract

In this paper a capacitive and an inductive fed rectangular dielectric resonator antenna (RDRA) have designed and analysed through 3D Electromagnetic Simulation Software HFSS. Solution frequency for analysing DRA taken as 3.97 GHz,maximum number of passes as 20,maximum delta S as 0.02 and sweep type as Fast. DRA made with Arlon AR1000(tm) with permittivity of 10 and patches are mounted on a FR_4 epoxy substrate with permittivity (ε_r) of 4.4. The capacitive feed DRA resonating maximum at 9.4GHz , produces return loss of -28.7809 dB, Q factor of 18.8, and 87% efficiency where as inductive feed resonates at 6.1 GHz produces return loss of –12.45 dB, Q factor of 40.66 , and 87% efficiency.

Keywords: *Rectangular Dielectric Resonator Antenna(RDRA), HFSS(High Frequency Structure Simulator), Capacitive feeding , Inductive feeding ,Arlon AR1000(tm), FR_4 epoxy*

I. INTRODUCTION

In 1939, R.D. Richmyer showed that non metalized dielectric objects can function similarly to metallic cavities which he called dielectric resonators (DRs).However practical application did not take place until 1960's when suitable dielectric compounds become available. The dielectric resonator has traditionally been used in filter and oscillator applications because its Q-factor can be made very high [1]. Significant development and great progress has been achieved in DR filter technology since the end of 1960's .The use of high permittivity DRs to enhance the radiation resistance of electrically short probes and loops was first suggested by Sager and Tisi in 1980 where as systematic experimental investigations on dielectric resonator antennas were first carried out by Long et al in 1983. Since then theoretical and experimental investigations have been reported by many investigators on DRAs of various shapes such as spherical, cylindrical, ring, rectangular etc and many techniques have been proposed to improve the bandwidth of DRAs, such as stacking multiple dielectric resonators, using parasitic DR elements etc [1- 6]. Recently, the multiple resonances techniques that was formerly employed in designing wideband micro strip antenna has been applied in DRA design .It is next generation low loss antenna due to its following properties, such as i) To support high data rate applications and to accumulate increasing number of users wide band antenna system need to be designed. ii)As lower microwave bands are very much crowded it is required to shift to higher frequencies of operations. iii) Microstrip Antennas have many advantages and is widely used for microwave bands but when it is used for higher microwave or mm frequency band of operation its performance is degraded due to increased conductor loss, hence DRA is the ultimate solution which can replace conventional microstrip antenna. DRA that is used for microwave frequency applications made with material having dielectric constant (ε_r) greater than 20 and quality factor(Q) between 50 and 500. In antennas as frequency increases conductor losses increases and the efficiency decreases, but the only losses present in DRA are due to imperfections in dielectrics and is very low compared to conductor loss.The radiation fields can be enhanced by choosing a dielectric material with permittivity between 5 and 20. The dimensions of DRA are of the order of $\lambda_0/\sqrt{\varepsilon_r}$ hence by choosinga high value of ε_r, the size of the antenna can reduce significantly.The basic difference between DRA and microstrip antenna is that the radiation in microstrip antenna happens due to narrow slots while in DRA it occurs due to the whole surface also it has a wider bandwidth as compared to microstrip antenna [8]. DRA can be excited by using many techniques like microstrip line, microstrip slot, coaxial probe,coplanar waveguide, etc...The rectangular-shaped DRA is simple to fabricate and have two aspect ratio such as (width/length and height/length) which gives extra functionality of control on DRA properties in the design process and provides a high degree of freedom in controlling antenna performance [9].

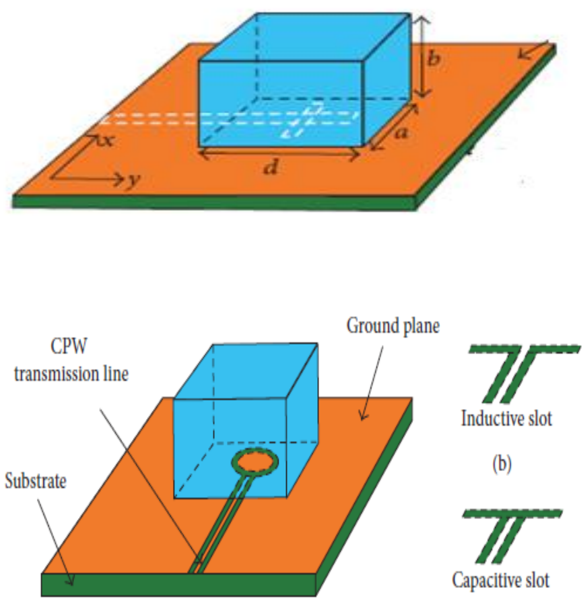

Fig.1. Rectangular DRA Fed by Co-Planar Waveguide[13]

The resonant frequency of a rectangular DR $a \times d \times b$ i:e (length* Width* height) is given by

$$F_r = \frac{c}{(2\sqrt{\varepsilon_r})[(p/L)^2+(q/W)^2+(r/H)^2]^{1/2}} \quad ....(1)$$

Or

$$F_r = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{k_x^2 + k_y^2 + k_z^2}$$

Where c is the velocity of light, ε_r=dielectric constant of DRA material, p,q,r are integers which represent the half-wave periodicity of electric field along the length(L), Width(W) and height(H). $K_x = \frac{\pi}{a}, K_z = \frac{\pi}{2b}, K_{Y0} = \sqrt{K_x^2 + K_z^2}$. Value of K_y can be determined by using the formula $d = \frac{2}{K_Y}\tanh\left(\frac{K_{Y0}}{K_Y}\right)$.The magnetic and electric field component along (X,Y,Z) direction can be derived by using the equation For a rectangular DRA with dimensions (width) > d (height)

$H_x = (k_x k_z/j\omega\mu_0)\sin(k_x x)\cos(k_y y)\sin(k_z z)$ (2)

$H_y=(k_y k_z/j\omega\mu_0)\cos(k_x x)\sin(k_y y)\sin(k_z z)$ (3)

$H_z=\{(kx^2 +k_y^2)/j\omega\mu_0 \}\cos(k_x y)\cos(k_y y)\cos(k_z z)$ (4)

$E_x=ky\cos(k_x x)\sin(k_y y)\cos(k_z z)$ (5)

$E_y=-kx\sin(k_x x)\cos(k_y y)\cos(k_z z)$ (6)

$E_z =0$ (7)

Where: $k_x^2+k_y^2+k_z^2=\varepsilon_r k_0^2$ (8)

$$k_z \tan\left(k_z \frac{d}{2}\right) = \sqrt{(\epsilon_r-1)k_0^2-k_z^2} \quad (9)$$

$$f_0=\frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{k_x^2 + k_y^2 + k_z^2} \quad (10)$$

If we consider TE_{111}^{y} mode, then the far-field radiation is similar to the magnetic dipole of moment P_m and is given by

$$P_m = -\frac{j8\omega\varepsilon_0(\varepsilon_r-1)}{k_{x1}k_{y1}k_{x1}}\sin(k_{y1}b/2) \quad (11)$$

The power radiated by a magnetic dipole and is given by P_y $k_0^4|P_m|$

The dielectric dissipated power,$P_d$is computed by using the following equations

$$P_d = \frac{1}{2}\omega_0\varepsilon_1 tan\delta \int_{-a/2}^{a/2}\int_{-b/2}^{b/2}\int_0^{c/2}|E|^2\, dzdydx = \omega_0 W \;\; tan\delta$$

(13)

$$P_c = \frac{1}{2}\sqrt{\frac{\omega_0\mu_0}{2\sigma_c}} \int_{-a/2}^{a/2}\left[\int_{-\infty}^{-b/2} |H_0|^2\, dy + \int_{-b/2}^{b/2} |H_d|^2\, dy + \int_{b/2}^{\infty} |H_\theta|^2 dy\right]\, dx - \int_{-w/2}^{w/2}\int_{-l/2}^{l/2} |H|^2\, dy\, dx]$$

Where tanδ = loss tangent of the dielectric
σ_c = conductivity of the ground plane
H_0 = magnetic field outside the DRA
H_d= field inside the dielectric resonator antenna

$$\frac{1}{Q} = \frac{1}{Q_r} + \frac{1}{Q_d} + \frac{1}{Q_c} = \frac{1}{W\omega_0}(P_r + P_d + P_c)$$

And the radiation efficiency η is given by

$$\eta = \frac{Q}{Q_r}$$

The field in the Dielectric resonator antenna is normalized such that

$$\int_{-a/2}^{q/2}\int_{-b/2}^{b/2}\int_{0}^{c/2} \mu_0\left(|H_{y\ 111}|^2\right)dz\ \ dy\ \ dz = 1.0$$

II. ANTENNA DESIGN METHODOLOGY

The proposed antenna design consists of a rectangular shaped resonator and a center-fed Capacitiveslot and inductive slot which is etched on an FR_4 substrate with dielectric constant 4.4. The rectangular-shaped resonator is placed above the substrate etched with the ground plane from the slot to the lower edge of the DR. The resonator material used is Arlon AR1000 (tm) has a dielectric constant of 10. Here L_s is the length of the substrate, W_s is the width of the substrate, L is the length of the rectangular resonator, W is the width, H is the height of the resonator.

TABLE 1.DIMENSIONS OF DIELECTRIC RESONATOR ANTENNA

Ground plane length	50 mm
Ground plane width	50 mm
Substrate Length	50 mm
Substrate width	50 mm
Substrate Thickness	3.2 mm
Resonator Length	20 mm

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Resonator Width	18 mm
Resonator Height	15 mm

The capacitive feed dielectric resonator antenna is shown in the figure below

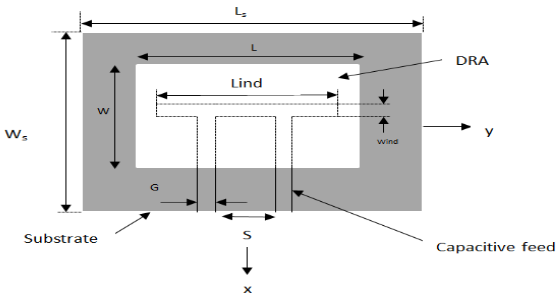

Fig.2.Top view of capacitive fed RDRA

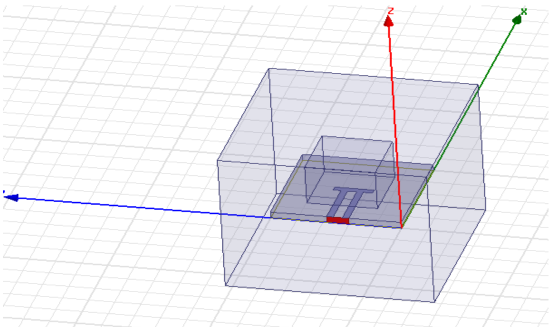

Fig.3.Design of capacitive fed RDRA

The inductive feed dielectric resonator antenna is shown in the figure below

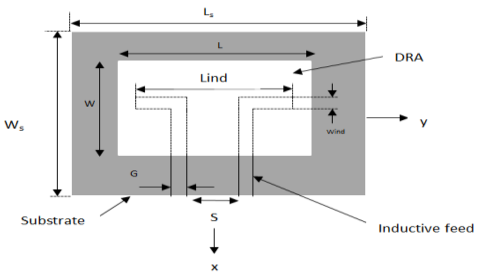

Fig.4.Top view of inductive fed RDRA

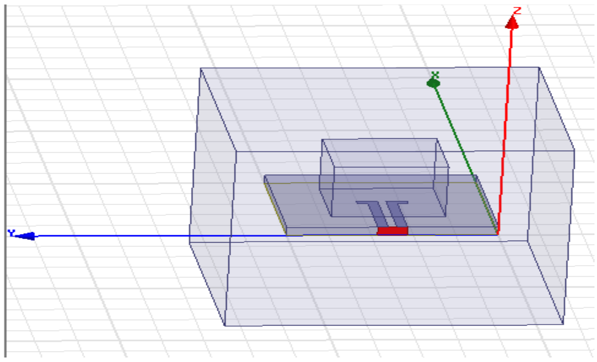

Fig.5.Design of inductive fed RDRA

III. SIMULATION RESULTS

The proposed capacitive and inductive feed dielectric resonator antennas are designed and simulated in HFSS. The designed antennas are analyzed in terms of gain, return loss, VSWR, and radiation pattern.

A. Return loss plot:

Figure.4and 5.Shows return loss [S_{11}] of the proposed capacitive and inductive feed DRA in dB. The plot gives the return loss at the feed position where the resonator antenna inputwas applied. The capacitive feed RDRA design produce -28.7809 dB return loss whereas inductive feed RDRA design produce -12.45 dBreturn loss

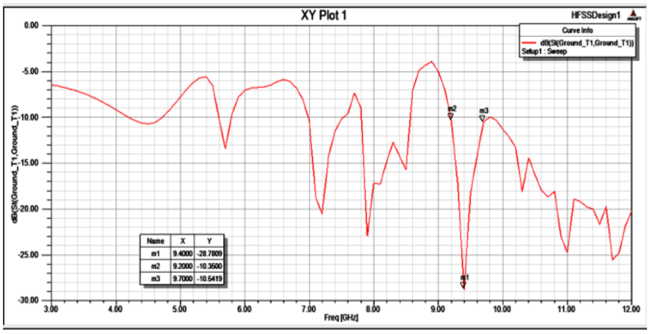

Fig.6. Return loss plot of capacitive fed RDRA

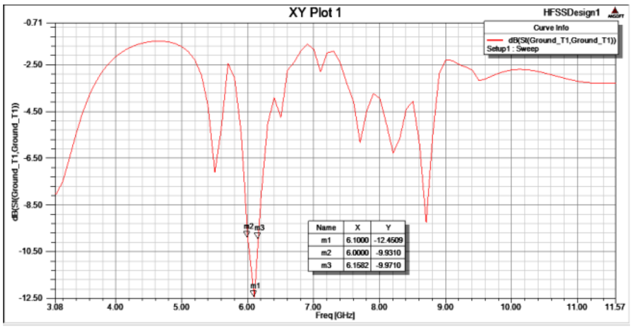

Fig.7. Return loss plot of inductive fed RDRA

B. *VSWR Plot:*

Fig.8 and 9. Shows the VSWR plot of capacitive and inductive feed DRA in dB.VSWRvalue of less than 2dB proves that impedance is perfectly matched and such design gives better performance compared to a higher value of VSWR. The capacitive feed RDRA design shows a VSWR of 0.6324 and inductive feed RDRA design shows a VSWR of 4.22

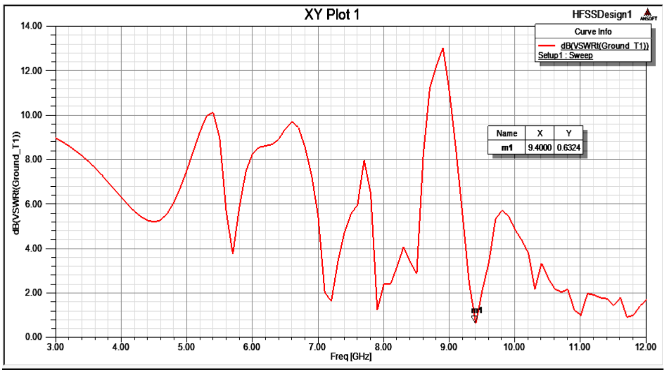

Fig.8. VSWR plot of capacitive fed RDRA

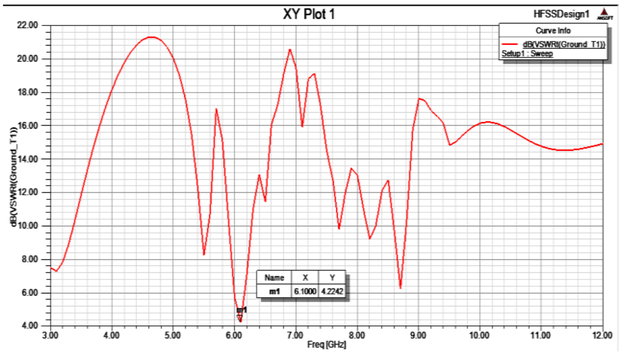

Fig.9.VSWR plot of inductive fed RDRA

C. *Radiation pattern:*

Fig.10 and 11 shows the 3D radiation patterns of capacitive and inductive fed RDRA

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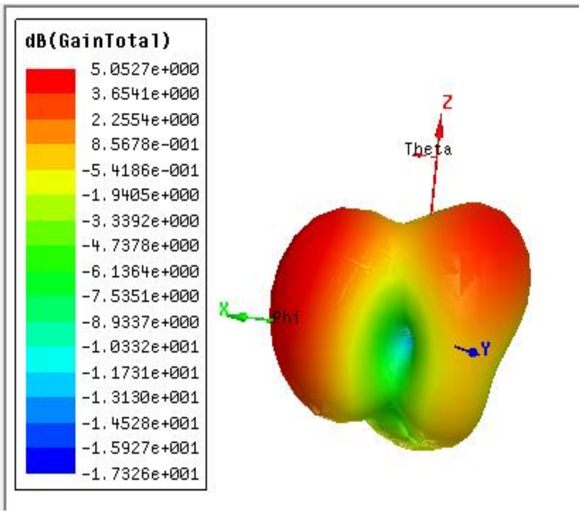


Fig.10. 3D polar plot of capacitive fed RDRA

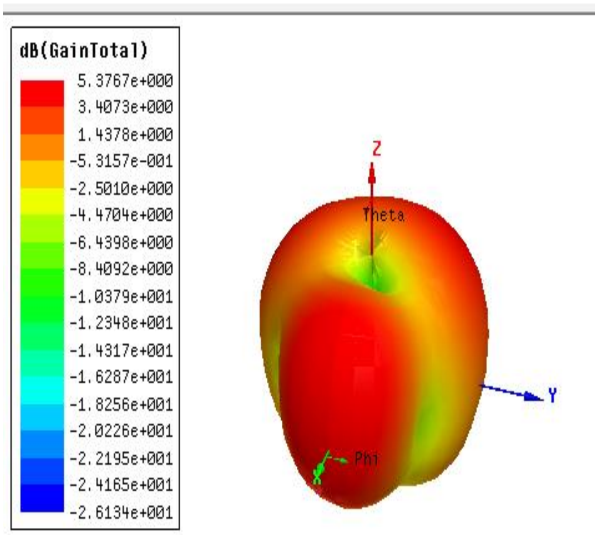
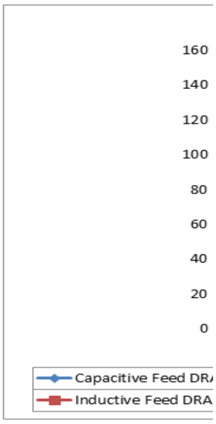


Fig.11. 3D polar plot of inductive fed RDRA

PARAMETERS	CAPACITIVE-FED RDRA	INDUCTIVE FED RDRA
Resonant frequency(GHz)	9.4	6.1
Max U (W/s_r)	0.0023636	0.00092031
Peak Directivity	3.659	3.4488
Peak gain	3.2009	1.1565
Peak Realized Gain	2.9703	0.67515
Radiated Power(W)	0.0081179	0.0029257
Accepted Power(W)	0.0092796	0.0033534
Incident Power(W)	0.01	0.01
Radiation Efficiency	**0.87481**	**0.87245**



Front to Back Ratio	81.634	151.09
Quality factor	18.8	40.66
%Bandwidth	5.29	0.8

Fig.12. Graphical representation of Computation parameters of Capacitive and Inductive fed RDRA

where

% Bandwidth=$(f_H - f_L) / ((f_H + f_L) / 2)$ (18)

Accepted power=Incident Power×$(1-S_{11}^2)$ (19)

Radiated power=Accepted power × Efficiency (20)

Gain=4πU / Accepted power (21)

Realized gain=4πU(Radiation Intensity) / Incident powe(22)

Directivity=4πU / Radiated power (23)

Radiated power=$4\pi U_{avg}$ (24)

Uavg= Radiated power / 4π (25)

Directivity=U_{max} / U_{avg} (26)

Gain=Efficiency ×Directivity (27)

Efficiency=Radiated power/Accepted power (28)

IV. CONCLUSION

The capacitive and inductive fed rectangular dielectric resonator antenna (RDRA) are designed using High Frequency Structure simulator software. The capacitive fed DRA is radiating at 9.4 GHz and inductive fed DRA is radiating at 6.1 GHz frequency. It has been found that the capacitive fed dielectric resonator antenna shows a return loss of -28.7809 dB, Q factor of 18.8,efficiency of 87%, front-to-back ratio of 81.634, while the inductive fed dielectric resonator antenna shows a return loss of – 12.45 dB, Q factor of 40.66, the efficiency 0f 87%, front-to-back ratio of 151.09. In terms of %bandwidth, the capacitive feed dielectric resonator is better while in terms of quality factor and front to back ratio the inductive fed dielectric resonator antenna is better.

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