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Performance Estimation of Cylindrical Dielectric Resonant Antenna

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Abstract*: This paper discusses the design and implementation of a cylindrical dielectric resonator antenna which is excited with HEM11δ as dominant mode using surface coaxial probe feed technique. The designed antenna radiates in the HEM11δ mode with a wide impedance bandwidth of over 2 GHz, and with a maximum gain of 5.93 dB thereby improving both gain and bandwidth compared to conventional micro strip patches. Further compared the characteristics of TE01δ and TM01δ modes with that of HEM11δ mode to prove the better radiation characteristics of the mode. By the proper selection of the parameter's antenna radiates in the entire C-band with a resonating frequency of 5.1 GHz. The designed antenna meets all the common features of the DRAs, but the main advantage is its ability to resonate with a considerably low- permittivity dielectric material.

***Keywords*: cylindrical dielectric resonator antenna (CDRA), surface coaxial probe feed technique, TM, TE, HEM11δ, DRA**

I. INTRODUCTION

Dielectric Resonator Antenna (DRA) is a radio antenna which works at high frequencies particularly microwave frequencies, made with ceramic materials and has a dielectric resonator which is mounted on a metal surface. The dielectric resonators are usually shielded to prevent radiation and thus maintain a high-quality factor, required for filter and oscillator designs. If the shielding is removed and a proper excitation to launch the appropriate mode is provided, the same dielectric resonators can become efficient radiators. Furthermore, by lowering their dielectric constant, the radiation can be maintained over a relatively broadband of frequencies.

Filters and oscillators, particularly micro strip technology. The radiation properties of CDR is used to examine the radiation characteristics of a probe- fed Cylindrical DRA. The CDRA is characterized by a height h, a radius a, and a dielectric constant ε_r. The cylindrical shape offers 10 of freedom than hemispherical shape and the aspect ratio 'a/h' determines f_o and the Q factor for a given dielectric constant. CDRA allows the designer to choose the most suitable aspect ratio for the desired frequency and bandwidth. Cylindrical shaped dielectric resonators have high Q factor and their compact size make them ideal for using in filters and oscillators, particularly micro strip technology. The radiation properties of CDR is used to examine the radiation characteristics of a probe- fed cylindrical DRA. The CDRA is characterized by a height h, a radius a, and a dielectric constant εr. The cylindrical shape offers 10 of freedom than hemispherical shape and the aspect ratio 'a/h' determines f_o and the Q factor for a given dielectric constant. CDRA allows the designer to choose the most suitable aspect ratio for the desired frequency and bandwidth.

Dielectric resonator reception apparatuses share a significant number of the benefits of micro strip antennas, including little size, low profile, light weight, simplicity of coupling to numerous sorts of transmission lines, and simplicity of combination with other dynamic or latent MIC components. The principle inspiration to plan a cylindrical dielectric resonator antenna is its capacity to use for reception apparatus applications by prudence of their high radiation productivity, flexible feed arrangement, simple geometry, little size and the capacity to create distinctive radiation pattern utilizing various modes. DRA's maintain a strategic distance from certain restrictions including the high conductor losses at millimeter-wave frequencies, sensitivity to tolerances, and narrow bandwidth. Feeding techniques like probe feed, aperture slot, micro strip line and coplanar line can be utilized with the DRAs which empowers them for joining with microwave printed innovation.

Unlike the hemispherical DRA, there is no precise solution for the fields of Cylindrical DRA. A typical methodology is to determine the fields for a CDR by expecting that the z-component of the magnetic field Hz is 0 at all surfaces parallel to the z- axis and the tangential electric and magnetic fields are continuous across surfaces parallel to the z-axis. Fields outside the resonators are expected to decay from their value at the boundary to zero at a boundless separation away. This magnetic wall boundary condition has been demonstrated to be substantial for higher values of εr however it stays a genuinely exact assumption for lower values as well.

The main objective is to structure a Cylindrical Dielectric Resonator Antenna (CDRA) for a desired C-band resonating frequency utilizing the design equations given in standard Dielectric Resonator Antenna Design handbooks. The ideal HEM11δ mode is excited as dominant mode for this configuration. Every one of the parameters, for example, field patterns, input impedance, return loss, gain, and radiation patterns are researched for this setup using EM simulator. The corresponding characteristics of TE01δ and TM01δ modes are additionally considered and thought about.

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The organization of the paper was as follows. Related literature was discussed in section II. The research methodology of the proposed design was reported in section III.

The problem statement of the current research was discussed in section IV. The analysis of the problem was explained in section V. The results obtained were presented in section VI. The obtained results were verified and validated in section VII. Finally, the conclusion is given in section VIII. Table I indicates resonant frequency by keeping the dielectric constant, ε_r and radius, a constant. Table II portraits resonant frequency by keeping the dielectric constant, ε_r and height, h constant. Table III shows resonant frequency by keeping the radius, a and height, h constant.

II. RELATED LITERATURE

The implementation of the CDRA antenna is completed by taking into thinking about the accompanying works. Cylindrical DRA was the primary antenna structure created from dielectric resonators on the ground that cylindrical structure provides more flexibility when contrasted with different shapes [1]. Cylindrical and rectangular dielectric resonator antennas using TE01δ, TM01δ and HEM11δ mode are analyzed to see the radiation pattern, impedance, and resonant frequency using Finite-difference time-domain simulation [2]. The essential test is the excitation of the mode in a practical DRA to reproduce a unique limit condition, which enunciates desired modal fields [3]. The numerical solution is based on the technique of bandwidth enhancement for dielectric resonators excited in the HEM11δ and HEM12δ modes [4] and a parametric report is done to recognize the upsides of DRA excited in the HEM mode [5]. The characteristics of CDRA antennas are investigated with both co-axial feeding and micro strip line feeding mechanism and the experiment is performed by coaxial and micro strip line feed and fabricated from BaZrO3 material of dielectric constant 27 [6]. Scattering parameters behavior and radiation patterns are determined by exploiting the geometrical symmetry of the structure, analyzing just a single half or one fourth of the whole area through two-or four-separate FDTD runs [7].

III. RESEARCH METHODOLOGY

The research started with mathematical modelling of cylindrical antenna for frequency of operation and quality factor which are function of radius and height of antenna. Using HFFS simulator estimated S-parameter and gain plot. Validation done by estimating frequency of operation for different modes like TE, TM and HEM modes by varying either radius(a) of antenna, height(h) of antenna and permeability (ε_r) of medium

IV. PROBLEM STATEMENT

Cylindrical dielectric resonator when used as radiator can be excited with any one of the following five lowest modes; TE01δ, TM01δ, HEM11δ, HEM12δ and HEM21δ. This consists of both resonating and non-resonating modes in which HEM11δ mode is the most suitable mode for antenna applications because of its radiation characteristics.

In this paper surface coaxial probe feed technique is adopted with HEM11δ mode to estimate the design parameters of the CDRA for a desired C-band resonating frequency. Comparison of the characteristics of HEM11δ mode with the more conventional TE01δ and TM01δ modes is also analyzed. An aspect ratio of 1:2.4, i.e. a radius of 10mm and a height of 12mm is considered and the radius of the coaxial probe is chosen to be 0.6375 mm. The dimensions of the ground plane used is 100 mm X 100 mm and dielectric constant of 4.4. The main challenge is to achieve a wide bandwidth and good radiation characteristics with this low εr material.

IV. ANALYSIS OF PROBLEM

The paper strategy is discussed in the following steps: Determine the radius and height: The radius of the antenna to be designed is first chosen followed by the selection of suitable height owing to the availability of materials. The ratio of radius to height forms the aspect ratio of the antenna. Here, a radius of 10mm and height of 12 mm is considered.

- Determine the Q factor: Based on aspect ratio Q factor is selected and is calculated using the standard equations available for each of the modes. For HEM11δ mode;

$$Q = 0.01007\varepsilon r^{1.3}\left(\frac{a}{h}\right)\left[1 + 100e^{-2.05\left[\frac{a}{2h}-\frac{1}{80}\left(\frac{a}{h}\right)^2\right]}\right] \quad \ldots\ldots (1)$$

- Determine the dielectric constant: Usually a DRA with $\varepsilon_r \leq 16$ is selected for bandwidth requirements irrespective of the a/h ratio. For designing DRA ε_r chosen is 4.4 which corresponds to the dielectric material FR4_epoxy.

- Determine the resonant frequency: In CDRA the equation for HEM11δ mode is

$$fo = \frac{6.324c}{2\pi a\sqrt{(\varepsilon r+2)}}\left[0.27 + 0.36\left(\frac{a}{2h}\right) + 0.02\left(\frac{a}{2h}\right)^2\right] \quad \ldots\ldots (2)$$

where; **a** is the radius of the cylinder, **h** is the height of the cylinder, $\boldsymbol{\varepsilon_r}$ is the permittivity.
Here CDRA is designed for the desired resonating frequency of f_0=5.09GHz. The corresponding equations of the TE01δ and TM01δ modes are;

$TE_{01\delta}$ mode:

$$fo = \frac{2.327c}{2\pi a\sqrt{(\varepsilon r+1)}}\left[1 + 0.2123\left(\frac{a}{h}\right) - 0.00898\left(\frac{a}{h}\right)^2\right] \quad \ldots\ldots\ldots (3)$$

$TM_{01\delta}$ mode:

$$fo = \frac{c}{2\pi a\sqrt{(\varepsilon r+2)}}\left[3.83^2 + \left(\frac{\pi a}{2h}\right)^2\right] \quad \ldots\ldots (4)$$

V1. RESULTS

The following section details about the results obtained using the electromagnetic simulator, Ansoft HFSS. Using this method, the CDRA is excited in the HEM11δ mode and its characteristics is compared with conventional TE01δ and TM01δ modes.

Figure 1 shows the obtained S- parameter plot. The mathematical equations reveal that the resonant frequency for HEM11δ mode occurs at 5.05 GHz. From the above graph the resonant frequency for the simulated CDRA occurs at 5.09 GHz thus confirming the validity of the design. The graph also tells that the antenna has a wide impedance bandwidth of 2.1 GHz, as indicated by the two markers m1 and m2. The HEM11δ mode appears throughout this band, thus making the antenna a broadband antenna. The corresponding TE01δ mode resonant frequency occurs at 5.597 GHz and TM01δ mode resonant frequency is at 7.639 GHz.

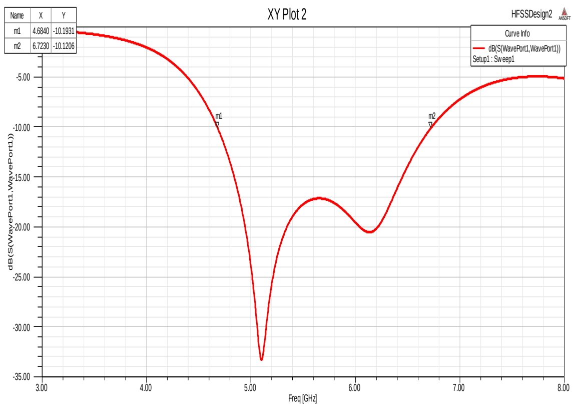

Fig 1. S-parameter plot

Figure 2 shows the obtained VSWR parameter plot. Figure 3 shows the obtained gain plot. From the graph it is visible that gain is much better than the micro strip patches. The inherent limitation offered by the cross-poles of H-plane is also depicted in the graph. The maximum gain obtained is of 5.93 db. The co-pole cross- pole separation is around 10 db. The cross-pole from E-plane has a wide separation and does not affect the antenna characteristics as shown in the figure 3.

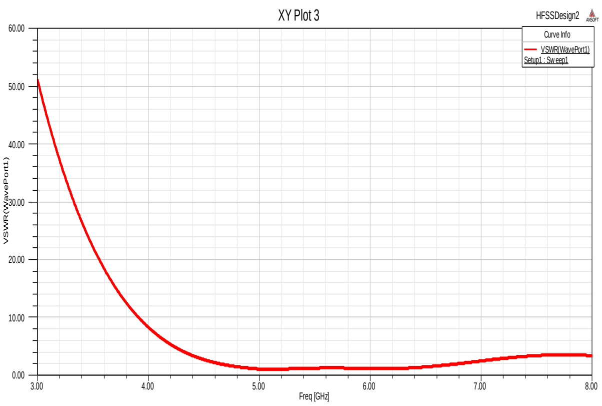

Fig. 2. VSWR plot

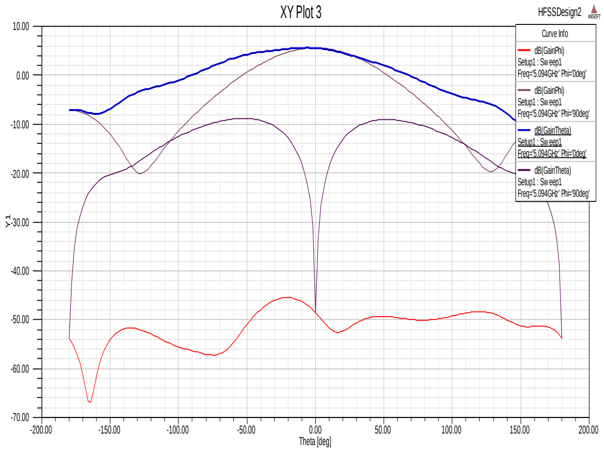

Fig 3. Gain Plot of designed CDRA

VII. VERIFICATION AND VALIDATION

The simulation results are validated by comparing the three modes of CDRA i.e., $TE_{01\delta}$, $TM_{01\delta}$ and $HEM_{11\delta}$ modes. Also, the resonant frequencies of the three modes are calculated by considering radius a, height h and dielectric constant ε_r. At a time only one parameter is varied, and the corresponding resonant frequencies are tabulated.

Table I: Keeping the dielectric constant, ε_r and radius, a constant

ε_r	a(mm)	h(mm)	fo (GHz) ($TE_{01\delta}$)	fo(GHz) ($TM_{01\delta}$)	fo(GHz) ($HEM_{11\delta}$)
4.4	10	3.2	6.2616	11.7502	10.5178
4.4	10	4.8	5.7912	9.5071	7.9564
4.4	10	5	5.7526	9.3484	7.7571
4.4	10	6.4	5.5473	8.5846	6.7243
4.4	10	9.6	5.2975	7.8597	5.5245

Table II: Keeping the dielectric constant, ε_r and height, h constant

ε_r	a(mm)	h(mm)	fo(GHz) ($TE_{01\delta}$)	fo(GHz) ($TM_{01\delta}$)	fo(GHz) ($HEM_{11\delta}$)
4.4	2.4	4.8	21.9918	30.7456	17.9655
4.4	3.2	4.8	15.9817	23.4154	14.6274
4.4	4.8	4.8	10.9945	16.2749	11.3125
4.4	6.4	4.8	8.4971	12.8717	9.6756
4.4	9.6	4.8	5.9923	9.7380	8.0883

Table III: Keeping the radius, a and height, h constant

ε_r	a(mm)	h(mm)	fo(GHz) ($TE_{01\delta}$)	fo(GHz) ($TM_{01\delta}$)	fo(GHz) ($HEM_{11\delta}$)
10	10	4.8	4.0305	6.8271	5.6649
15	10	4.8	3.3644	5.8322	4.8818
20	10	4.8	2.9637	5.1277	4.2913
30	10	4.8	2.4171	4.2517	3.5582
40	10	4.8	2.1017	3.7111	3.1058

VIII. CONCLUSION

This paper encompasses the design and analysis of cylindrical dielectric resonator antenna (CDRA), excited with HEM11δ as dominant mode using surface coaxial probe feed technique. The designed antenna radiates in the entire C-band with a resonant frequency of 5.09 GHz. The main accomplishment of the project is to obtain the radiating characteristics of the CDRA using a low dielectric constant material FR4_glass epoxy, with a permittivity as low as 4.4.

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