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An Array of Four Cylindrical Dielectric Resonator Antenna for Wideband Monopole Like Radiation

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***Abstract* - The main aim to present this paper is to increase the bandwidth of the dielectric resonator antenna (DRA). A four element cylindrical dielectric resonator antenna (CDRA) array above the ground plane is introduced here. CDRA is very easy to design and excited with HE11δ mode excited in each CDRA by centrally placed dielectric resonator in which TM01δ mode excited. In this paper the effect of design parameters such as permittivity of materials, height of probe, radius of cylinders and the arrangement of dielectric layers investigated and the excited modes are also been confirmed by simulations. The simulation is performed on CST Microwave studio. The introduced cylindrical dielectric resonator antenna (CDRA) can offer an impedance bandwidth of ~23.08% for return loss below -10dB where frequency range is from 3.57 to 4.50 and resonance frequency is 3.98GHz with monopole like radiation pattern and it is stable in the passband with a gain of 1.560dB.**

KEYWORDS- Dielectric Resonator (DR) ,Dielectric resonator antenna (DRA), Impedance Band Width (IBW), Cylindrical Dielectric Resonator Antenna (CDRA), Reflection Co-efficient (S_{11}).

I. INTRODUCTION

Dielectric resonator antennas (DRAs) have been proposed during the last two decades and significant advances are being made in developing them for many applications. One major aspect of the research with DRA is how to enhance the element bandwidth as evident from survey of open literature, e.g., [1]–[3]. For DRAs with broadside radiation, different shapes [4]–[6] and composite structures [1], [7], [8] have been investigated. For monopole type radiation pattern, only a few handful investigations with DRAs are available in open literature. The TM01 mode in coaxial feeding dielectric ring resonator was used to generate monopole-like radiation in [9]. The narrow impedance bandwidth of the structure in [9] was improved by introducing an air gap between the DRA and the ground plane in [10], [11]. Two broadband variants of dielectric ring resonator have recently been proposed in the form of coax-fed disc-ring [12] and rod-ring [13] combinations, respectively. An electric monopole-fed dielectric ring has been reported as an ultra wideband antenna in [14]. In this paper, we present a new approach with a four element cylindrical dielectric array where the HEM11δ mode is excited in each DRA element and the composite field patterns result in a uniform monopole-like radiation pattern over a wide bandwidth [15]. Some previous studies [16], [17] also used four element probe-fed cylindrical DRA (CDRA) but their array elements were arranged in a conventional way and their aim was to study the broadside linearly polarized radiation with shaped directional patterns using HEM11δ mode.

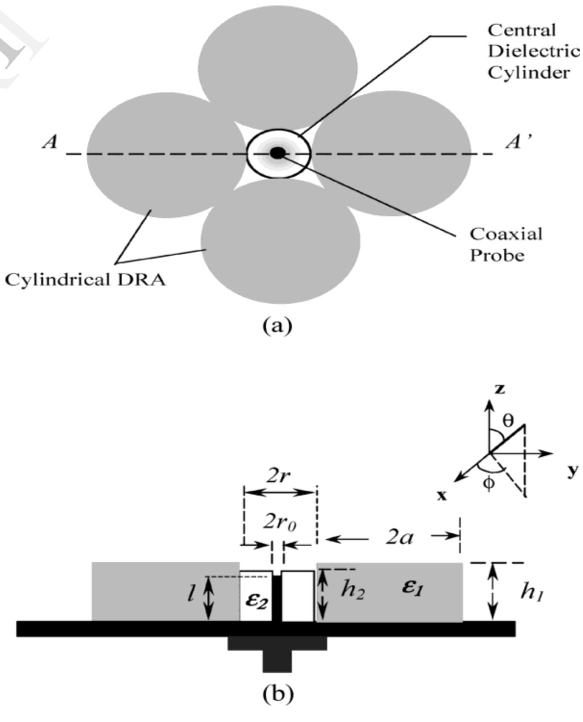

Fig. 1. Four-element cylindrical DRA fed by a central coaxial probe.(a) Top view, (b) cross-sectional view at AA plane.

From a practical point of view, it is easy to design the CDRA array excited with the dominant HEM11δ mode than a ring resonator with mode as the latter one suffers from the inherent narrow bandwidth. The antenna geometry is shown in Fig. 1 and is described in Section II. Though this consists of more numbers of dielectric blocks compared to the previous designs, it shows some added advantages like simple design without much optimization of parameters, easy excitation of HEM11δ mode in each CDRA element and planar geometry with compact size. The design parameters were determined using analytical formula and then optimizing through simulation studies as described in Section III. The excited resonant modes responsible for monopole-like radiation over a wide operating frequency are critically examined and discussed in Section III.

II. THEORY

The resonant frequency is one of the important parameters needed to design this dielectric resonator antenna. The approximate calculation of resonant frequency for the TM01δ mode and HE11δ mode for conventional cylindrical DRA can be done by following expressions.

For TM01δ

The resonant frequency calculated by-

$$Fr = \frac{c}{2\Pi a\sqrt{(\varepsilon_r + 2)}}\sqrt{3.28^2 + \frac{\Pi a}{2h}} \qquad (1)$$

And radiated Q factor is calculated by-

$$Q_{rad} = 0.008721\varepsilon_r^{0.888413}e^{0.0397447} \times\left\{1-\left(0.3-0.2\frac{a}{h}\right)\left(\frac{38-\varepsilon_r}{28}\right)\right\} \times\left\{9.498186\frac{a}{h}+2058.33\left(\frac{a}{h}\right)^{4.32226}e^{-3.5\left(\frac{a}{h}\right)}\right\} \qquad (2)$$

Where *a, h, and* ε_r are radius, height and dielectric constant respectively of dielectric resonator.

For HE11δ

The resonant frequency calculated by-

$$F_r = \frac{6.324}{a\sqrt{\varepsilon_r + 2}}\left\{0.27 + 0.36\left(\frac{a}{2h}\right) + 0.02\left(\frac{a}{2h}\right)^2\right\} \qquad (3)$$

Q-factor given by-

$$Q_{rad} = 0.01007\varepsilon_r^{1.3}\left(\frac{a}{h}\right)\left\{1+100e^{-205\left(\frac{a}{2h}\frac{1}{80}\left(\frac{a}{h}\right)^2\right)}\right\} \qquad (4)$$

The radiation *Q*-factor can be used to estimate the fractional impedance bandwidth of a DRA-

$$Bandwith(BW) = \frac{VSWR - 1}{Q_{rad}\sqrt{VSWR}} \qquad (5)$$

In order to achieve large fractional impedance bandwidth the *Q*-factor should be less and this can be possible only when low dielectric constant materials are used which is clear from equation (2) and (4), and it also depends upon the (*a/h*) ratio. In this paper we maintain (*a/h*) as 1 so that fractional impedance bandwidth is mainly function of dielectric constant. Here multilayer concept of dielectric is introduced in dielectric resonator antenna to enhance the fractional bandwidth. From relations (1) to (5), it is clear that if the dielectric constant of the material gets higher, both the resonant frequency and bandwidth will decrease and if dielectric constant gets lower, both the resonant frequency and bandwidth increases. So for multilayer DRA, lower dielectric constant section improves the bandwidth and higher dielectric constant section helps to lower the resonant frequency and vice-versa. Arrangement of different permittivity in a DR is decided based on simulation results. For exciting the TM01δ mode in central DR probe coupling is used. The amount of coupling can be optimized by adjusting the probe height as well as optimal dielectric constant used for central dielectric resonator.

PARAMETERS-
h- height of probe,
h_1=height of cdra,
h_2= height of cylinders
ε_{r1} = dielectric constant of cylinder 1,
ε_{r2} = dielectric constant of cylinder 2,
ε_{r3} = dielectric constant of cylinder3, ε_{r4} = dielectric constant of cylinder 4,
ε_{cdra} = dielectric constant of cdra

III.THE ANTENNA CONFIGURATION

A four-element cylindrical DRA (CDRA) is schematically shown in Fig. 1. Each candidate of the composite structure is of height h_1, radius a and different relative permittivity $\varepsilon_{r1}, \varepsilon_{r2}, \varepsilon_{r3}$ and ε_{r4} and they are packed together in a compact way on a metallic ground plane (GP). The array is centrally excited by a coaxial probe of height h and radius r_0 which itself is surrounded by a small dielectric rod of radius r, height h_2 and relative permittivity ε_{rcd}. It actually touches the surfaces of all four CDRAs. Since with, the small dielectric rod acts as a modified probe touching each CDR and helps in launching fields from probe to CDRAs. From simple calculation it can be shown that the radius of the central dielectric rod r=(√2-1)a is a limiting value when all four CDRAs come closest to each other and maintain physical contacts amongst themselves as shown in Fig.1. This is the design value for the proposed antenna. A probe touching a CDRA surface is suitable for exciting the dominant HEM11δ mode [18], and thus the feed arrangement in our proposed antenna can easily excite each CDRA element with the dominant HEM11δ mode. The resulting electric field in individual CDRA is linearly polarized as described in [19]. When four CDRAs, as in Fig. 1, are simultaneously excited, the composite electric field patterns look like that shown in Fig. 9(a), obtained from simulation data. It is apparent that the electric field components lying on XY-plane face their counter vectors and thus cause null radiation along the broadside of the antenna. Rather, the resultant electric fields are polarized along Z-axis and thus lead to a vertically polarized radiation surrounding the radiating structure like a quarter wave electric monopole. Since both the monopole and the composite CDRA structure effectively produce identical radiation fields, uniform monopole-type pattern can be achieved over the full matching bandwidth.

IV. DESIGN AND RESULTS

For studying the characteristics of the proposed antenna our initial considerations for each CDRA were, ε_{r1}=9.4, ε_{r2}=9.9, ε_{r3}=8.6, ε_{r4}=10 and , ε_{rcd}=15, a=2mm and h1=12mm $HEM_{11\delta}$,and and the mode resonant frequency in an individual element was calculated as 3.91 GHz using the design formula [20]

$$F r = \frac{C}{2\pi a\sqrt{\varepsilon_{r-1}}}\left[1.71+\frac{a}{h}+0.1578\left(\frac{a}{h_1}\right)^2\right] \qquad (6)$$

Where C is the velocity of light in free space. The value of ε_{rcd} was chosen on the basis of commercially available high dielectric constant material and the resulting optimum input impedance matching was studied using Ansoft's microwave studio cst . For simulating the structure we have used the wave port mode of excitation for the coaxial feed and the radiation boundary was fixed at a distance of, being the free space wavelength corresponding to the lowest component of the frequency sweep. Fast sweep mode has been employed to generate the results and a few samples were verified using the results obtained from discrete sweep mode. Good agreement was revealed in each case. Maximum ΔS

I. (S-parameter) value of 0.01 was chosen for terminating the adaptive solution and this gives accurate simulation results. Some representative results for different antenna parameters are shown through Figs. 3–5. The height if the central dielectric close to that of each CDRA shows good impedance matching and as such has been chosen for the present studies. The effect of the relative permittivity of the central dielectric rod is shown in Fig. 3.
II. In the table-1 we showed the possible impedance bandwidth at different dielectric constant of four cylinders and central dielectric resonator antenna (CDRA).
III. And in the table -2 we have shown the possible bandwidth and impedance bandwidth at different dielectric constant of central dielectric resonator antenna (CDRA).

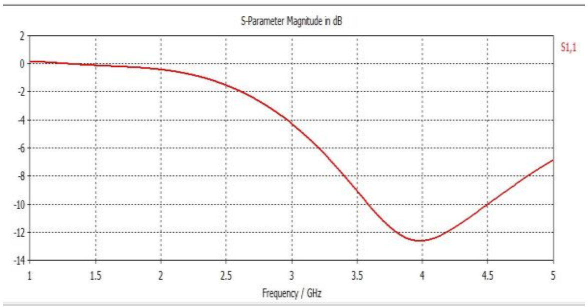

Fig 2. Simulated return loss of four elements CDRA. [*a* = 2 mm, $h_1 = 10mm, h_2 = 12mm$ and $h = 8mm$, *r* = .828 mm, $\varepsilon_{rcd} = 15$, $r_o = 0.1mm$ and *hp*= 8 mm]

TABLE.I IMPEDANCE BANDWIDTH AT DIFFERENT DIELECTRIC CONSTANT OF CYLINDERS AND CDRA ARRANGEMENT

[*a* = 2 mm, $h_1 = 10, mm, h_2 = 12mm$ and $h = 8mm$, *r*=.828 mm, $h_c = 3mm$ $\varepsilon_{rcd} = 15$, $r_o = 0.1mm$

Cylinder$_1$ (ε_{r1})	Cylinder$_2$ (ε_{r2})	Cylinder$_3$ (ε_{r3})	Cylinder $_4$ (ε_{r4})	CDRA (ε_{cdra})	Impedance Bandwidth (%)
9.4	9.9	8.6	10	15	23.08

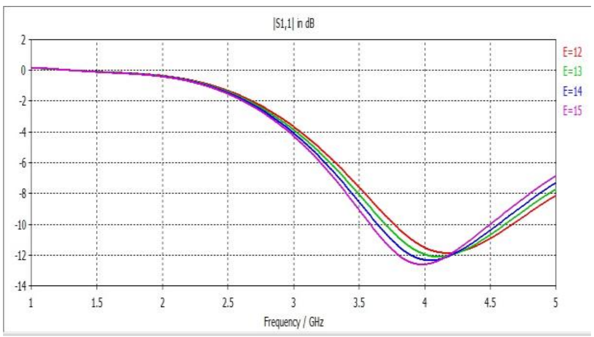

Fig. 2(b). Simulated return loss of four element CDRA for different dielectric constant of the central DRA [*a* = 2 mm, $h_1 = 10mm, h_2 = 12mm$ and $h = 8mm$, *r* = .828 mm, , $\varepsilon_{rcd} = 15$, $r_o = 0.1mm$]

TABLE II. BANDWIDTH AND IMPIDANCE BANDWIDTH AT DIFFERENT DIELECTRIC CONSTANT OF CDRA

[a = 2 mm, $h_1 = 10, mm, h_2 = 12mm$ and $h = 8mm$, r = .828 mm, $h_c = 3mm$ $\varepsilon_{rcd} = 15$, $r_o = 0.1mm$]

Dielectric Constant(ε_{cdra})	Bandwidth(GHz)	Impedance Bandwidth $\left(\frac{F_H - F_L}{F_C}\right)\%$
ε_{cdra} = 12	0.91	21.66
ε_{cdra} = 13	0.92	22.21
ε_{cdra} = 14	0.91	20.9
ε_{cdra} = 15	.93	23.08

The optimal design parameters are for the four element CDRA is a = 2 mm, $h_1 = 10, mm, h_2 = 12mm$ and $h = 8mm$, r = .828 mm, $\varepsilon_{cdra} = 15$, $r_o = 0.1mm$

The return loss below −10dB where frequency range is from 3.57 GHz to 4.50 GHz and resonance frequency is 4.04 GHz shown in Fig. 3, corresponding to that the percentage impedance bandwidth of ~23.08% has been obtained.

The Far field radiation pattern at f =3.98 GHz can be shown in Fig4 which shows a maximum gain of 1.507 dBi.

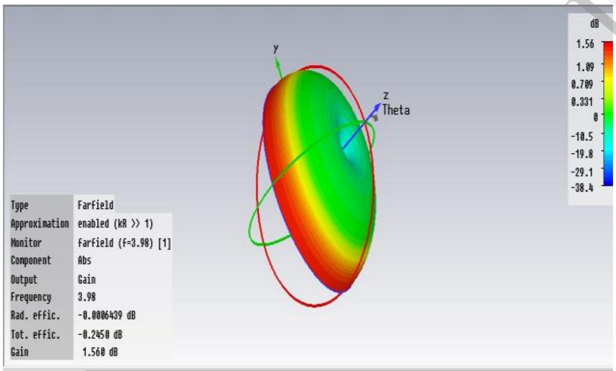

Fig.3. 3-D view simulated gain of the four element cylindrical dielectric [a=2mm, mm $h_1 = 10mm, h_2 = 12mm$ and $h = 8mm$, r = .828 mm, $\varepsilon_{cdra} = 15, r_o = 0.1mm$]

IV. CONCLUSION

The wide four element cylindrical dielectric resonator antenna (CDRA) is proposed with coaxial probe excitation. It is simply excited by central DR which is located in the center of three element arrangement where TM01δ mode is excited in central DR and HE11δ mode is excited in each CDRA element. The mode patterns have been confirmed by H-field distribution in central DR and each CDRA. The return loss curve shows 36% impedance bandwidth (S11 < −10dB) with monopole like radiation pattern which is stable in the pass band with the gain 1.56 dB at 3.98 GHz. The proposed antenna is suitable for C-band application like in WiMAX.

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