Abstract—The main objective of the present study is to improve the bandwidth of the dielectric resonator antenna (DRA). A new four-element multilayer cylindrical dielectric resonator antenna (MCDRA) array above the ground plane is proposed here. MCDRA is easy to design and excited with $HE_{11\delta}$ mode excited in each MCDRA by centrally placed dielectric resonator in which $TM_{01\delta}$ mode excited. The effect of design parameters such as permittivity of materials, probe height and arrangement of dielectric layers are investigated and the excited modes (i.e. $TM_{01\delta}$ and $HE_{11\delta}$) are also been confirmed by simulations. The simulation is performed on Ansoft's HFSS package. The proposed multilayer cylindrical dielectric resonator antenna (MCDRA) can offer an impedance bandwidth of $\sim 47\%$ for the return loss below $-10\text{dB}$ where frequency range is from 4.06 to 6.07 GHz and resonance frequency is 4.3 GHz with monopole like radiation pattern and it is stable in the passband with 4.73 dB gain.

Keywords— Dielectric resonator (DR), dielectric resonator antenna (DRA), multilayer cylindrical dielectric resonator antenna (MCDRA), monopole-type antenna, probe coupling.

I. INTRODUCTION

The dielectric resonator (DR) was used as an energy storage device rather than a radiator in microwave circuits for many years [1] but open dielectric resonators (DRs) offer attractive features as antenna elements. These include their small size, mechanical simplicity, high radiation efficiency due to no inherent conductor loss, relatively large bandwidth, and simple coupling schemes to nearly all commonly used transmission lines, and the advantage of obtaining different radiation characteristics using different modes of the resonator [2]. The experimental investigation of the resonant cylindrical dielectric cavity antenna capable of providing efficient radiation done by Long et al. [3]. The radiation Q factor of a DR antenna depends on its excitation modes as well as the dielectric constant of the ceramic material. The Q-factor increases and hence the bandwidth decreases with increasing dielectric constant and vice-versa. For this reason, DR's of relatively low dielectric constant are almost always used in antenna applications [4]. The bandwidth enhancement in DRA is most interesting area for researchers, there are several techniques was developed by many researcher e.g. using coupling mechanism like probe, slot & microstrip feed etc., stacking of DR with different permittivity materials, its aspect ratios, and DRA with air gap etc.

Figure 1. Four-element and three layer cylindrical DRA with layered central dielectric cylinder fed by central coaxial probe. (a) Top view, (b) cross-section view at XX' plane.
The first experimental research is carried out for wideband DRA in 1989 by Kishk et al., in this work input impedance of stacked cylindrical dielectric resonator antennas is investigated experimentally and the dielectric resonators are made of different materials, and the bandwidth of 25% has been observed [5]. The bandwidth enhancement in DRA is introduced by Guha et al., by introducing four-element cylindrical dielectric resonator array as a wideband low profile monopole-like antenna [6]. By using this approach nearly 29% impedance bandwidth \((S_{11} < -10 \text{ dB})\) with uniform monopole-like radiation pattern over the entire band is achieved. The multilayer multi-permittivity approach has been studied for higher mode separation in dielectric resonator in microwave integrated circuit (MIC) environment [7].

In this article, we have proposed multilayer concept in four-element cylindrical dielectric resonators (CDR) array for wideband antenna application. The central DR is located at the center of four element multilayer CDR arrangement as shown in Fig. 1. The \(T_{M01}\) mode is excited in central DR and hence \(H_{E11}\) mode would be excited in each multilayer CDR element. The return loss, radiation patterns, and antenna gain of proposed structure are simulated using the Ansoft’s High Frequency Structure Simulator (HFSS).

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 \(T_{M01}\) mode and \(H_{E11}\) mode for conventional cylindrical DRA can be done by following expressions [1].

**For \(T_{M01}\)**

The resonant frequency calculated by

\[
f_r = \frac{c}{2\pi a \sqrt{\varepsilon_r + 2}} \sqrt{3.83^2 + \left(\frac{\pi a}{2h}\right)^2}
\]

and radiated Q factor is calculated by

\[
Q_{\text{rad}} = 0.008721 \varepsilon_r^{0.888413} e^{0.397447} \left[ 1 - \left(0.3 - \frac{0.2\varepsilon_r}{\varepsilon_r + 2} \right) \right] \times \left\{ 9.498186 \frac{a}{h} + 2058.33 \left(\frac{a}{h}\right)^2 e^{-3.5\left(\frac{a}{h}\right)} \right\}
\]

**For \(H_{E11}\)**

The resonant frequency calculated by

\[
f_r = \frac{6.324}{a \sqrt{\varepsilon_r + 2}} \left\{ 0.27 + 0.36 \frac{a}{2h} + 0.02 \left(\frac{a}{2h}\right)^2 \right\}
\]

Q-factor given by

\[
Q_{\text{rad}} = 0.01007 \varepsilon_r^{1.3} \frac{a}{h} \left[ 1 + 100 e^{-200\left(\frac{a}{2h} - \frac{1}{10.4}\right)^2} \right]
\]

where \(a, h,\) and \(\varepsilon_r\) are radius, height, and dielectric constant respectively of dielectric resonator.

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

\[
\text{Impedance Bandwidth (BW)} = \frac{\text{VSWR}-1}{Q_{\text{rad}} \times \text{VSWR}} = \frac{\Delta f}{f_0}
\]

where \(\Delta f\) and \(f_0\) are absolute bandwidth and resonant frequency respectively.

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 \(T_{M01}\) 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.

III. ANTENNA CONFIGURATION AND SIMULATION RESULTS

A. Antenna Configuration

Fig. 1 shows the proposed four-element and three layer cylindrical DRA, where each MCDRA having radius \(a\), layer heights \(h_1, h_2\) and \(h_3\) with dielectric constant \(\varepsilon_r1, \varepsilon_r2\) and \(\varepsilon_r3\) respectively. The dielectric constant of central DR is \(\varepsilon_{rCD}\) with radius \(r\) and height \(h_c\). The arrangement of DRAs is
shown in Fig. 1, where it is placed on metallic ground plane. This arrangement of MCDRA is excited with central probe of height \(h_p\) and radius \(r_o\), which itself surrounded by central DR. The radius of central dielectric resonator is calculated by \(r = (\sqrt{2}-1)a\), for this value of \(r\), central dielectric cylinder resonator touches to all the MCDRAs. The purpose of maintaining this physical contact among probe, central DR and MCDRA is to give the path to fields to reach from probe to the MCDRA for getting good matching. The \(TM_{01}\) \(\delta\) mode [8] is excited in central DR by coaxial probe and this central DR works as probe to excite the \(HE_{11}\delta\) mode [8] in each MCDRAs.

**B. Design and Parametric Results**

Before the characterization of the proposed four element MCDRA, we have to find the optimal arrangement of dielectric layers for getting higher impedance bandwidth. For this purpose the arrangement of dielectric layers of one element MCDRA has optimized initially for higher impedance bandwidth. The geometry for one element MCDRA with coaxial probe excitation is shown in Fig. 2. The optimized dimensions for one element MCDRA are obtained as the radius of each dielectric layer (\(a\)) = 10mm, height of bottom layer (\(h_1\)) = 3.5 mm, height of middle layer (\(h_2\)) = 3.0 mm and height of top layer (\(h_3\)) = 3.5 mm.

So the optimal arrangement for three dielectric layers from bottom to top are Polyflon Polyguide (\(\varepsilon_r^1 = 2.32\)), Roger RT/Duroid 6006 (\(\varepsilon_r^2 = 6.15\)), Roger RT/Duroid 6010 (\(\varepsilon_r^3 = 10.2\)) with dielectric layer height are from bottom to top \(h_1 = 3.5\) mm, \(h_2 = 3.0\) mm, \(h_3 = 3.5\) mm respectively.

Now for studying the characteristics of proposed four element MCDRA, the initial study has been performed for different dielectric constant of central DR for good input impedance matching.

Fig. 3 shows the return loss for proposed four element MCDRA as a function of frequency for different combination of central DR dielectric constant.

![Figure 3. Simulated return loss of four element MCDRA for different dielectric constant of the central DR. \([a = 10\) mm, \(h_1 = 3.5\) mm, \(h_2 = 3.0\) mm, \(h_3 = 3.5\) mm, \(r = 4.14\) mm, \(h_c = 10.0\) mm, \(h_p = 7.8\) mm, \(r_o = 0.55\) mm] (Fig. 3)](image)

![Figure 4. Simulated return loss of four element MCDRA for different probe height. \([a = 10\) mm, \(h_1 = 3.5\) mm, \(h_2 = 3.0\) mm, \(h_3 = 3.5\) mm, \(r = 4.14\) mm, \(h_c = 10.0\) mm, \(\varepsilon_{rcd} = 6\), \(r_o = 0.55\) mm] (Fig. 4)](image)

Fig. 3 shows that wider bandwidth and good impedance matching can be achieved when the dielectric constant of the central DR is 6. After obtaining the optimal Central DR dielectric constant, now it is required to find the optimal probe length for wider bandwidth and impedance matching.

Table I. Impedance bandwidth of different dielectric layer arrangement

<table>
<thead>
<tr>
<th>Bottom Layer ((\varepsilon_r^1))</th>
<th>Middle Layer ((\varepsilon_r^2))</th>
<th>Top Layer ((\varepsilon_r^3))</th>
<th>Impedance Bandwidth (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.15</td>
<td>10.2</td>
<td>2.32</td>
<td>14.0</td>
</tr>
<tr>
<td>10.2</td>
<td>6.15</td>
<td>2.32</td>
<td>4.4</td>
</tr>
<tr>
<td>6.15</td>
<td>2.32</td>
<td>10.2</td>
<td>18.2</td>
</tr>
<tr>
<td>2.32</td>
<td>6.15</td>
<td>\textbf{10.2}</td>
<td>\textbf{32.7}</td>
</tr>
<tr>
<td>10.2</td>
<td>2.32</td>
<td>6.15</td>
<td>27.7</td>
</tr>
<tr>
<td>2.32</td>
<td>10.2</td>
<td>6.15</td>
<td>31.7</td>
</tr>
</tbody>
</table>
Fig. 4 shows the return loss versus frequency with different probe heights, and the wider and strong matching is observed at $h_p = 7.8$ mm.

C. Optimal Simulation Results

The optimal design parameters for the four element MCDRA are $a = 10$ mm, $h_1 = 3.5$ mm, $h_2 = 3.0$ mm, $h_3 = 3.5$ mm, $r = 4.14$ mm, $h_c = 10.0$ mm, $\varepsilon_{rcd} = 6$, $r_o = 0.55$ mm, $h_o = 7.8$ mm. The return loss below $-10$dB where frequency range is from 4.06 to 6.07 GHz and resonance frequency is 4.3 GHz as shown in Fig. 5, corresponding to that the percentage impedance bandwidth of $\sim 47\%$ has been obtained.

The simulated VSWR of four element MCDRA shown in Fig. 6. The matching frequency range is from 4.06 to 6.07 GHz where the VSWR < 2. Fig. 7 shows the real and imaginary part of simulated input impedance. It is clear that the resonance frequency corresponds to the point where the imaginary part of the input impedance is zero and correspondingly the real part is 49.3 which shows the good matching.

![Figure 5](return_loss.png)  
Figure 5. Return loss for four element MCDRA. $[a = 10$ mm, $h_1 = 3.5$ mm, $h_2 = 3.0$ mm, $h_3 = 3.5$ mm, $r = 4.14$ mm, $h_c = 10.0$ mm, $\varepsilon_{rcd} = 6$, $r_o = 0.55$ mm, $h_o = 7.8$ mm.]

![Figure 6](vswr.png)  
Figure 6. VSWR for four element MCDRA. $[a = 10$ mm, $h_1 = 3.5$ mm, $h_2 = 3.0$ mm, $h_3 = 3.5$ mm, $r = 4.14$ mm, $h_c = 10.0$ mm, $\varepsilon_{rcd} = 6$, $r_o = 0.55$ mm, $h_o = 7.8$ mm.]

![Figure 7](input_impedance.png)  
Figure 7. Simulated input impedance for four element MCDRA. $[a = 10$ mm, $h_1 = 3.5$ mm, $h_2 = 3.0$ mm, $h_3 = 3.5$ mm, $r = 4.14$ mm, $h_c = 10.0$ mm, $\varepsilon_{rcd} = 6$, $r_o = 0.55$ mm, $h_o = 7.8$ mm.]

![Figure 8](h_field.png)  
Figure 8. H-field distribution at frequency 4.3 GHz for four element MCDRA. $[a = 10$ mm, $h_1 = 3.5$ mm, $h_2 = 3.0$ mm, $h_3 = 3.5$ mm, $r = 4.14$ mm, $h_c = 10.0$ mm, $\varepsilon_{rcd} = 6$, $r_o = 0.55$ mm, $h_o = 7.8$ mm.]
The distribution of H field in four-element MCDRA is shown in Fig. 8, it is clear that around central DR magnetic field is in equatorial plane (i.e. \( z = h_c \) plane) and \( H_z \) component is zero. Therefore \( TM_{01\delta} \) mode is excited in central DR and \( HE_{11\delta} \) mode is excited in each MCDRA.

![Image of simulated gain at 4.3 GHz](image)

Figure 9. 3-D view of simulated gain at 4.3 GHz. \([a = 10 \text{ mm}, h_1 = 3.5 \text{ mm}, h_2 = 3.0 \text{ mm}, h_3 = 3.5 \text{ mm}, r = 4.14 \text{ mm}, h_c = 10.0 \text{ mm}, \varepsilon_{r\text{cd}} = 6, r_o = 0.55 \text{ mm}, h_p = 7.8 \text{ mm.}]\)

The far field, 3-D view of total gain of proposed structure is shown in Fig. 9, which shows the maximum gain of 4.73 dB.

IV. CONCLUSION

The wide band four element multilayer cylindrical dielectric resonator antenna (MCDRA) is proposed with coaxial probe excitation. It is simply excited by central DR which is located in the center of four element MCDRA arrangement where \( TM_{01\delta} \) mode is excited in central DR and \( HE_{11\delta} \) mode is excited in each MCDRA element. The mode patterns have been confirmed by H-field distribution in central DR and each MCDRA. The return loss curve shows 47% impedance bandwidth (\( S_{11} \prec -10 \text{dB} \)) with monopole like radiation pattern which is stable in the passband with the gain of 4.73 dB at 4.3 GHz. The proposed antenna is suitable for C-band application like in WiMAX.

REFERENCES


