A Compact Liquid Based Cylindrical Dielectric Resonator Antenna for S Band

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I. INTRODUCTION
DRAs have attracted increasing attention due to their simple structure, flexible feeding techniques, low loss and high radiation efficiency. Unlike conductive antennas, the influence of nearby objects (such as human hands) has not much effect on the performance of a DRA, which is one of the major reasons for DRAs becoming popular in some portable devices [1]. Since size of an antenna decreases with the increase in the permittivity of the resonator material, compact resonator antennas can be realized using materials of high permittivity. A substantial amount of research effort has been devoted to the study of DRAs in the last decade. Solid dielectric materials with high permittivity and low loss are mostly used for DRAs. However, DRAs using liquid dielectric has not been studied much in literature. Liquid DRAs [2,3,4,5] are easier to build and can have any desired shape. In addition, the feeding structures and other additional external devices can be easily placed within the liquid dielectrics without introducing air gaps, which is not easy for solid dielectrics.

There is normally a trade-off between the antenna size and its bandwidth. Recently a few planar structures are proposed using log periodic array or using parasitic elements [6,7], those are capable of giving wide frequency coverage. However, these structures are not much simple and also have large volume. In order to design a small DRA with simple structure, material with large permittivity is required, however, it gives narrow bandwidth. The small size, simple cylindrical DRA proposed in this paper is capable of giving a wide frequency coverage in S band.

II. ANTENNA DESIGN
Both radius (a) and height(h) of cDRA are taken as 10mm. Duroid of $\varepsilon_r = 2.2$ is used for designing outer cylindrical shell of cDRA, both inner radius (b) and inner height(hi) of the shell is 8mm. Normal water ($\varepsilon_r \sim 77$) is used to fill up the inner cylinder. The proposed structure is shown in Fig.1. Here a probe is used for exciting the DRA. Different modes can be excited in a cylindrical DRA. $\text{HE}_{11\delta}$ mode of a cylindrical DRA can be excited with a probe located adjacent to (or slightly inset into) the DRA [8]. The probe length is generally chosen to be less than the height of the DRA. Here probe length is taken as 4mm and is placed at a distance of 6.36mm from the center of the cylinder.

![Fig. 1 Proposed cylindrical dielectric resonator antenna](image)

Resonant frequency of $\text{HE}_{11\delta}$ mode can be calculated from the following formula [9] for cDRA.

$$f_0 = \frac{2 \times 10^{10}}{2\pi \sqrt{\varepsilon_r}} \sqrt{\frac{2(\delta/4)^2 + \frac{\pi^2}{2\delta}}{2\delta}} \quad (1)$$

Since dielectric constant ($\varepsilon_r \sim 77$) of water is much greater than that of duroid ($\varepsilon_r = 2.2$) which is used for the
outer shell, contribution from the water cylinder is considered only for calculation of frequency. Variation of dielectric constant of water with frequency is also taken into consideration following [10]. Resonant frequency for the proposed structure comes out to be 3.3GHz using Eqn.(1). Thus, the structure can be used in S band.

III. RESULTS AND DISCUSSIONS

CST microwave studio software is used for simulation of the above structure. Fig.2 shows results for cDRA for three different ground plane structures. From Fig.2 it is seen that dual frequency operation, one near 2.5 GHz and the other near 3.1 GHz, is possible with this structure since return loss is very small near these frequencies. The second minimum return loss frequency corresponds with resonant frequency calculated from eqn.1 for HEM11δ mode. Directive gain of the structure with ground plane radius equal to the cDRA radius is found to be only 2.1 dBi. However, directive gain can be increased by increasing the area of ground plane. It is seen from Fig.2 that when ground plane dimension is increased, minimum return loss frequency remains almost the same as before, however, maximum gain is increased. Fig.3(a) shows that maximum gain becomes 3.7dBi for 160mmX160mm square ground plane, Fig.3(b) shows that if shape of the ground plane is made circular with diameter 160mm, gain is further increased and becomes 4.7dBi.

Now a metal sheet of width 8mm and height 9 mm is introduced in the structure along the diameter. Results for three different thicknesses of the metal sheet are shown in Fig.4. It is seen from the Figure that when thickness of the sheet becomes 6mm, 10dB impedance bandwidth of 1.4GHz extending from 2.3GHz to 3.7GHz is obtained. From Fig 5, it is seen that gain value more than 7dBi is obtained in this range of frequency.

Fig.2 $S_{11}$ vs. Frequency for cDRA. Graph 1 for ground plane just covering bottom of DRA, Graph2 for 160mmX160mm square ground plane, Graph3 for 160mm diameter circular ground plane

Fig.3(a) Far field plot for 160mmX160mm square ground plane
Fig. 3(b) Far field plot for 160mm diameter circular ground plane

Fig. 4 Plot of return loss with metal sheet of width 8mm, height 9mm and of different thicknesses

Fig. 5 Radiation pattern for metal sheet of 6mm thickness
TABLE I
COMPARISON OF THE PROPOSED ANTENNA STRUCTURE

<table>
<thead>
<tr>
<th>Reference</th>
<th>ε_r</th>
<th>f_r (GHz)</th>
<th>BW (GHz)</th>
<th>Gain (dBi)</th>
<th>Volume (cm^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[11]</td>
<td>10.12</td>
<td>3.3</td>
<td>0.96</td>
<td>4</td>
<td>13.1</td>
</tr>
<tr>
<td>[12]</td>
<td>8.9</td>
<td>1.9</td>
<td>0.22</td>
<td>6.4</td>
<td>34.3</td>
</tr>
<tr>
<td>[13]</td>
<td>10</td>
<td>3.2</td>
<td>1.12</td>
<td>5</td>
<td>16.75</td>
</tr>
<tr>
<td>[14]</td>
<td>9.5</td>
<td>3.68</td>
<td>0.77</td>
<td>5</td>
<td>515.2</td>
</tr>
<tr>
<td>[15]</td>
<td>9.5</td>
<td>3.5</td>
<td>0.74</td>
<td>5</td>
<td>4.09</td>
</tr>
<tr>
<td>[16]</td>
<td>10</td>
<td>3.5</td>
<td>1.05</td>
<td>2.5</td>
<td>16.75</td>
</tr>
<tr>
<td>PS</td>
<td>2.2, f dependant</td>
<td>3.09</td>
<td>1.5</td>
<td>7.9</td>
<td>3.14</td>
</tr>
</tbody>
</table>

ε_r = dielectric constant, f_r = resonant frequency (GHz), BW = bandwidth (GHz), Gain = measured in dBi, Volume = volume occupied by the antenna (cm^3), PS = Proposed Structure (case of cDRA with metal sheet).

Table 1 shows the comparison of the proposed DRA with different S band DRAs found in literature. It is evident from the table that the proposed DRA has the lowest volume, highest gain and largest bandwidth.

IV. CONCLUSION

A probe fed DRA using distilled water within a cylindrical shell of duroid is designed and its performance is investigated using CST microwave studio. The effect of extended ground and the effect of insertion of a metal sheet shows dual frequency operation at 2.4GHz and 3.2GHz. Enhancement of bandwidth and improvement of gain occurs with the insertion of the metal sheet. 10dB impedance bandwidth extending from 2.3GHz to 3.7GHz and maximum gain 7.9 dBi are achieved at the frequency of 3.09 GHz when metal sheet of width 8mm, height 9mm and thickness 6mm is inserted within the DRA.

REFERENCES

