Use of Symmetry Planes in Two Excitation Modes of the Cylindrical Dielectric Resonator Antenna

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Abstract – This paper explores the use of symmetry planes used to divide hybrid modes of resonance in cylindrical dielectric resonator antennas (DRAs). Apart from the traditional groundplane mirror used to support the DRA, mirrors are examined which divide the $\text{HEM}_{11\delta}$ and $\text{TE}_{01\delta}$ modes. The antennas were evaluated using FDTD numerical simulation techniques. The results show practical antennas can be created which have mono-lobed radiation patterns and/or the volume of the antenna can be reduced.

I. INTRODUCTION

DIELECTRIC RESONATOR Antennas (DRAs) have become popular in recent times due to their high efficiencies at microwave frequencies. These antennas are normally constructed from a low loss dielectric material, usually a ceramic, mounted on a ground plane. Excitation of the antenna may be achieved by a coaxial probe inserted into, or next to, the dielectric body, or by a microstrip under the groundplane with an aperture through it under the dielectric.

Fields are excited inside the resonator and will draw most power from the feed when excited in a resonant mode. It is this field which radiates. Modes exist that radiate an omnidirectional pattern in azimuth, or that have multi-lobe patterns in azimuth. The $\text{HEM}_{11\delta}$ mode is the fundamental mode for the cylinder. This mode may be excited by an offset probe. The field radiates with a figure-of-eight pattern produced from the magnetic dipole distribution within.

The multi-lobe radiation patterns can be useful for some applications but most applications require a single lobe. Utilising the symmetry planes within the resonant mode often allows the DRA to produce fewer lobes. It also usually reduces the volume, and thus weight, of the DRA. Implementing the symmetry usually involves placing metallic dividers through the DRA in places where the internal fields have a plane of symmetry. One half of the DRA is then usually removed.

II. EXPERIMENT

Two cylindrical DRA structures were examined. The first consisted of a dielectric cylinder placed over a ground plane. The cylinder has dimensions and permittivity as shown in figure 1. A probe was placed on a radius halfway to the outer edge the cylinder in such a position to excite the $\text{HEM}_{11\delta}$ mode. This mode is supported by two horizontal contra-rotating H field loops diametrically opposed. The probe is placed in the centre of one of these. Because of the symmetry of the field lines in this mode a conducting plane may be placed in the centre of the cylinder, as also shown in figure 1, without affecting the resonant mode. The plane in this case does not extend past the edges of the dielectric. Note the probe length was changed in the half cylinder. The second cylindrical structure consists of a cylindrical DRA in free space and its half cylindrical equivalent bisected by a ground plane through a diameter of the cylinder. The structure and dimensions for this antenna are shown in figure 2. This DRA should resonate in the $\text{TE}_{01\delta}$ mode. Excitation was again by a probe. In the case of the half cylinder it was placed perpendicular to the ground plane as shown. The probe in the full cylindrical structure was a dipole probe placed symmetrically as shown in figure 2.

FDTD model: The $\text{HEM}_{11\delta}$ mode DRA’s were modelled using 1 mm cells in bounded and non graded cartesian simulation spaces of approximately 100 x 100 x 60 cells. Berengers Perfectly Matched Layer (PML) Absorbing Boundary Conditions (ABC) were used to terminate the simulation space. The PML thickness was 4 cells with a parabolic conductivity profile. The residual reflection
levels for this structure at the frequencies of interest were approximately -70 dB. Since the split-field approach was used for the PML ABC, separate computational regions were used for efficient memory usage. The DRA structures were placed on an infinite perfectly conducting groundplane and fed with gap excitation at the base of the probe. The TE$_{01\delta}$ mode cylindrical structure, being of much smaller dimensions, was simulated with a 0.2 mm grid and similar boundary and ground plane conditions. A gaussian pulse of $40\times10^{-12}$ seconds was used for gap excitation to obtain the impedance and radiation pattern simulations whilst sinusoidal gap excitation was used to obtain snapshots of the E and H fields in the resonator.

An IBM SP2 supercomputer at the Queensland Parallel Supercomputing Facility (QPSF) was used for the computations with IBM RS/6000 Wide nodes. Typical computation times were in the order of 20-30 hours, running on a single node, due to the highly resonant behaviour of DRAs. In all simulations the dielectric was modelled as lossless.

### III. RESULTS

**Resonant Frequency:** The resonant frequency of the full cylindrical DRAs were calculated and the return loss, of all DRA’s, were extracted from the FDTD simulation in order to ascertain the resonant frequency of each antenna. The return loss for the HEM$_{11\delta}$ mode cylindrical DRA is shown in figure 3 for full and half structures. The error between calculated resonant frequency and minimum return loss frequency from the simulation for the full cylinder HEM$_{11\delta}$ mode DRA was found to be 15 MHz or 1.4%. Resonant frequencies for the full cylinder HEM$_{11\delta}$ mode was 1.03 GHz and the -10 dB return loss bandwidth was 99 MHz (9.6%). For the half cylinder the resonant frequency was 1.09 GHz with a bandwidth of 83 MHz (7.6%). As expected the resonant frequency of the half DRA’s had shifted. A finite dimensioned metal divider was not expected to fully mirror the fields as some fields would be expected to spill around the ends of the divider.

![Fig. 3 Simulated return loss for the full and half HEM$_{11\delta}$ mode cylindrical and TE$_{01\delta}$ mode rectangular DRA.](image)

The resonant frequency of the TE$_{01\delta}$ mode cylindrical DRA was found to be 5.74 GHz with a -10 dB bandwidth of 475 MHz, or 8.3%, as shown in figure 4. This occurred with an overall probe length of 6.8 mm.

![Fig. 4 Simulated return loss for the TE$_{01\delta}$ mode full and half cylindrical DRA.](image)

Simulating the half cylinder TE$_{01\delta}$ mode DRA revealed an optimum length for the probe to be 3.2 mm. The resonant frequency, as shown in figure 4, was found to be 6.43 GHz.. The -10 dB return loss bandwidth is 730 MHz or approximately 11.4%. The resonant frequency of the half cylinder DRA is significantly higher than the frequency of the full cylinder.

**Field distributions:** By viewing the field distribution within the DRA one may understand firstly the mode in which the DRA is resonating, and secondly may be able to make adjustments to the DRA shape, size and probe position to maximise operation in the required mode. Being able to view these fields also helps in understanding the expected radiation pattern and how modification to the structure will influence the pattern. In order to examine only those fields due to one resonant mode within the DRA the excitation must be at one frequency only.

The FDTD model was re-run with sinusoidal excitation fixed at the resonant frequency of each DRA as defined by the minimum return loss. A snapshot of the field intensity and direction was taken in a cut through each resonator. The cuts were generally positioned in the dielectric, but above the exciting probe. The H fields only are displayed in figures 5 and 6. As expected the divider in the half cylindrical HEM$_{11\delta}$ mode DRA was quite effective in containing the field with only a little spillage around the end of the divider. Also some field distortion is to be expected as the natural field distribution may not be able to exist due to the probe enforcing the field pattern at the excited pole.

The half cylinder TE$_{01\delta}$ mode DRA H field distribution is shown in figure 6. The two XY and XZ cuts demonstrate how the cylinder can be divided by the ground plane without interfering with the fields for that mode. The infinite groundplane divides the DRA without any field spillage which occurred with the two previous examples.
Fig. 5 H field distribution for the XY plane in the full and half cylindrical HEM₁₁δ mode DRA (Z = 26 mm).

Fig. 6 H field distribution for the XY plane (Z=2.8 mm) and XZ plane (Y=centre) for the TE₀₁δ mode cylindrical DRA.

Radiation Patterns: The patterns for variations in θ(XZ plane) and φ(XY plane) are plotted in figure 7 for the full and half HEM₁₁δ mode DRA’s at each antenna’s respective resonant frequency. The radiation patterns for both full structures show the expected figure-eight pattern caused by the ‘magnetic dipoles’. The probe can be thought of as a small segment from a vertically oriented current carrying loop. A magnetic field exists in the horizontal plane around this probe and also in the opposite direction around the image of this probe, diametrically opposite in the DRA. This arrangement produces the fields that might be expected from two small diametrically opposite segments taken from a loop antenna, and is often called a magnetic dipole. This gives a similar radiation pattern, in azimuth, to a loop antenna. The patterns show improved directionality for the half DRA in both cases. Also the elevation angle for maximum radiation has been reduced for both half DRA’s.

Figure 8 shows the radiation patterns for the TE₀₁δ mode half cylindrical DRA. The pattern is half toroidal and fairly symmetrical. The full cylindrical version pattern is not shown but was the expected figure-eight pattern in both XY and XZ planes.

IV. DISCUSSION AND CONCLUSIONS

It can be seen that DRA’s may be constructed using half of the volume of the normal structure thus taking up half the space and weighing nearly half as much. The resonant frequency of the half DRA is altered slightly from that of a full DRA by between 6% and 12%. The effect is most significant for the TE₀₁δ mode and it is observed that the shift in frequency is upwards for both the HEM₁₁δ and TE₀₁δ mode half cylindrical DRA’s. The bandwidth of the DRA’s also vary from full to half symmetry. Both cylindrical DRA’s experienced an increase in bandwidth when halved.

The half DRA also demonstrates a more directional radiation pattern than the full DRA. It is anticipated that directionality may also be further improved by extension of the conducting plane that divides the DRA. This should reduce the amplitude of the rear lobe. Both the HEM₁₁δ mode half DRA’s and the TE₀₁δ mode DRA would seem suitable for satellite applications however the HEM₁₁δ mode DRA’s may find application for terrestrial antennas due to their lower radiation angles.

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REFERENCES
