Investigation on Rudimentary Geometries of Dielectric Resonator Antenna

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Abstract— Due to the variety of geometries available to antenna designers such as rectangular, cylindrical, hemispherical etc., a proper practice to select the best geometry for Dielectric Resonator Antenna (DRA) is required. In this paper, various rudimentary geometries of DRA excited by a coaxial probe fed is designed and investigated for selecting the preeminent geometry of antenna. The rudimentary geometries of DRA are rectangular, cylindrical and hemispherical, which are used for investigation of DRA performance. The dielectric material used for rudimentary geometries is TMM10i, a ceramic thermoset polymer composite material of the Rogers high-frequency laminates.The DRA is designed to operate around 3.2 GHz. However, the resonant frequency may alter due to different rudimentary geometries. CST Microwave Studio transient solver is used to design and simulate the different rudimentary geometries of DRA.These rudimentary geometries of DRA give a better understanding of design parameters of an antenna and their effect on return losses, impedance bandwidth, VSWR, gain, efficiency and resonant frequency.

1. INTRODUCTION

Since 1960s, DRs have been used as high Q factor components in shielded microwave devices and circuits such as microwave filters, oscillators and cavity resonators [1]. In 1983, Long et al. observed that by removing the metallic shielding and with the proper feeding to excite the appropriate mode, it was found that the DRs could actually become efficient radiators [2]. The open DRs are potentially useful antenna elements. They carried out systematic study and an experiment investigation of radiation property of cylindrical, spherical and rectangular shaped antennas and their studies confirmed that the DRAs could be considered to be superior alternatives compared to the traditional antennas like monopoles, dipoles and microstrip patch antennas.

DRA has been investigated extensively in the past few decades due to its attractive features such as high radiation efficiency, zero conductor losses, wide bandwidth, and ease of fabrication [3, 4]. A DRA is a high radiation efficiency radiator, which is usually made up of high permittivity lossless dielectric material. Today, with the rapid development of wireless communications, wideband DRAs have received tremendous attention.As compared to cylindrical or hemispherical DRA, Rectangular Dielectric Resonator Antenna (RDRA) provides more degrees of freedom which can be used to control the impedance bandwidth of the antenna [3].

Significant efforts on DRAs have been reported to achieve wide bandwidth such as introducing an air gap between the DRA and ground plane [5], multilayer stacking of dielectric materials [6], fractal approach on DRA [7], etc.. Thus, a regular study to select the basic geometry of DRA is required for wireless applications. For the design of such type of DRA system, different rudimentary geometries of DRAs are required. These rudimentary geometries of DRAs play a very important for antenna society with a wide range of antenna's applications. To analyze several geometries, basic shapes of DRAs are considered and designed to resonate around 3.2 GHz.

In this paper, three rudimentary geometries of DRAs fed by coaxial probe are investigated. $|S_{11}|$ plot, radiation efficiency, radiation patterns and antenna gains were studied using CST Microwave Studiotransient solver [8]. To validate the research work, simulation was carried out, and reasonable agreement is obtained.

2. ANTENNA CONFIGURATION

Different shapes of DRA have different modes of resonance, and hence different field distribution, radiating properties and resonant frequencies. Since the analytical methods cannot be used for most shapes, multiple methods were found in order to analyze the fields inside DRs. From fields inside DRs, resonant frequencies and radiation characteristics of certain modes can be determined [4]. A dielectric waveguide model (DWM) method of analysis is very good approximation for regular structure of DRs. According to the DWM method of analysis, it can be assumed that the resonator is a truncated section of an infinite dielectric waveguide having transverse dimensions same as of the DR [9].

For the rectangular shape, the modes will also have an orientation dependency, due to symmetry. Hence, the lower energy modes are $TE^x_{\delta 11}$, $TE^y_{\delta 11}$ or $TE^z_{\delta 11}$ [10]. These modes radiate similar to a short magnetic dipole in the x, y or z direction. In cylindrical DRA, $HME_{11\delta}$ and $TM_{01\delta}$ resonant modes are radiated [3,4] but other higher order modes excitation is also possible while the fields present in the hemispherical DRA shape can be divided into two distinct modes: TE_{111} and TM_{101} [11].

The resonant frequency of hemispherical DRA (HDRA) can be found using following equations [4]:

$$f_{r\,(\mathrm{GHz})} = \frac{4.7713\mathrm{Re}\left(k(hr)\right)}{r\sqrt{\varepsilon_r}} \tag{1}$$

For TE$_{111}$ Mode:

$$\mathrm{Re}(k_r) = 2.8316\varepsilon_r^{-0.47829} \tag{2}$$

For TM$_{101}$ Mode:

$$\mathrm{Re}(k_r) = 4.47226\varepsilon_r^{-0.505} \tag{3}$$

The resonant frequency of cylindrical DRA (CDRA) is given as [3,4,12]:

$$f_{TE_{01\delta}} = \frac{2.237}{\sqrt{\varepsilon_r + 1}}\left(1 + 0.2123\frac{r}{h} - 0.00898\left(\frac{r}{h}\right)^2\right).\frac{4.7713}{r} \tag{4}$$

The resonant frequency (f_r) of a rectangular DRA (RDRA) is given as [13,14]:

$$f_r = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{k_x^2 + k_y^2 + k_z^2} \tag{5}$$

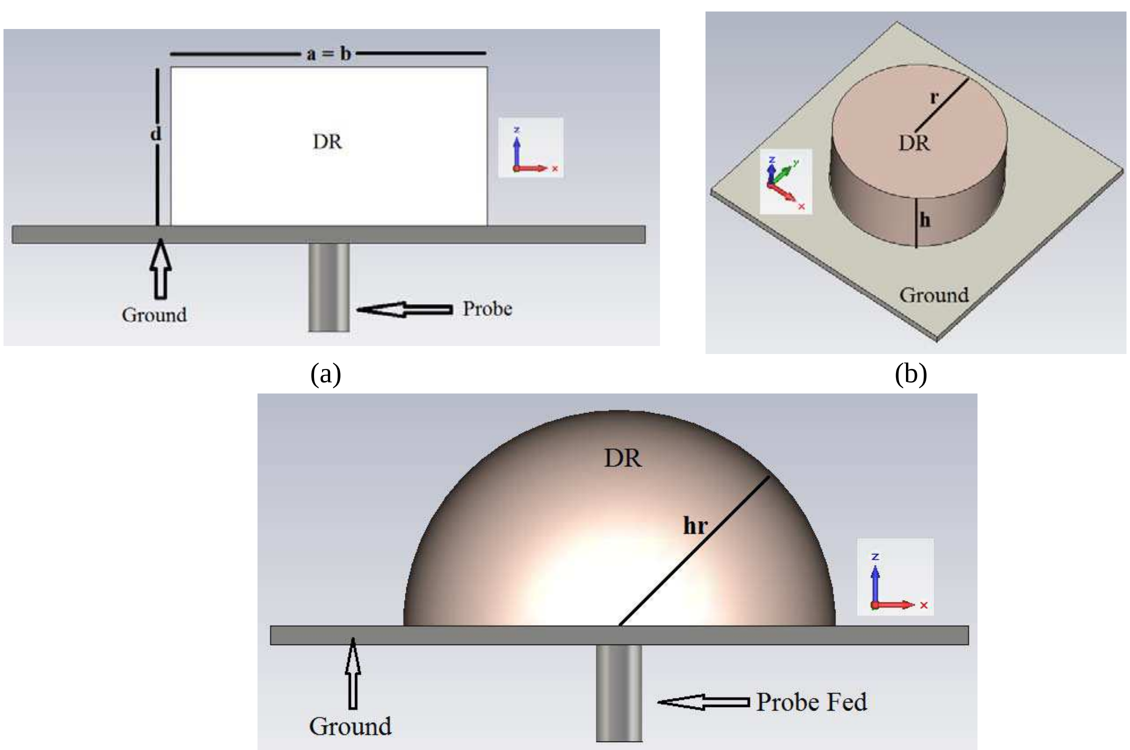

Figure 1: Configuration of rudimentary geometries of DRA: (a) rectangular, (b) cylindrical, (c) hemispherical.

In Eqs. (1)–(4) "ε_r" is the dielectric constant of the RDRA, "c" is the speed of light in free space and symbol "k_x", "k_y" and "k_z" represents the wave numbers in the x, y and z directions respectively. The dielectric material used for simulation is Roger TMM10i, a ceramic thermoset polymer composite material of the Rogers high-frequency laminates [15]. The dielectric constant (ε_r) of the material is 9.8, the dissipation factor ($\tan\delta$) is 0.002, and the density is 2.8 gm/cm^3.

The geometry of the proposed DRA is shown in Figure 1. DRA is designed on symmetrical ground plane having the dimension of $60 \times 60\,\text{mm}^2$. For Rectangular DRA,the dimensions along x-, and y-,directions are equal ($a = b = 30\,\text{mm}$) and along z-,direction is d ($d = 15\,\text{mm}$). While for cylindrical DRA radius of r ($r = 18\,\text{mm}$) and height h ($h = 15\,\text{mm}$) is taken. However, for hemispherical DRA the dimension of radius is hr ($hr = 18.61\,\text{mm}$).

3. RESULTS AND DISCUSSION

Figure 2 shows the variations of $|S_{11}|$ verses frequency for different rudimentary geometries of DRAs. The simulated result shows thatthe impedance bandwidth (for returnloss below $-10\,\text{dB}$) of the RDRA is 56%, 46% and 50% for rectangular, hemispherical and cylindrical respectively.

Gain plots of all three geometries are shown in Figures 3–5. The peak gain is measured at 3.2 GHz, which is 1.56 dB for Rectangular DRA, 1.50 dB for Cylindrical DRA and 1.54 dB for Hemispherical DRA respectively.

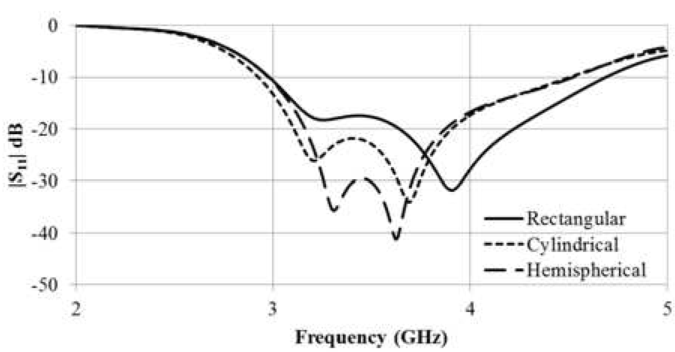

Figure 2: Variations of $|S_{11}|$ verses frequency for different rudimentary geometries of DRAs.

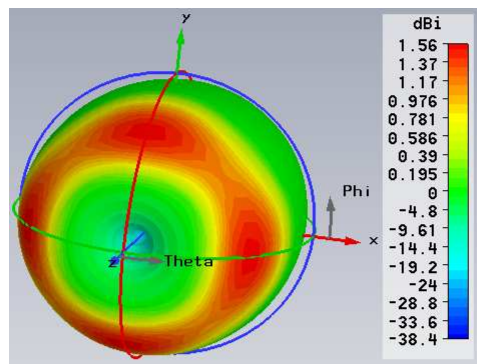

Figure 3: Gain plot of RDRA at 3.2 GHz.

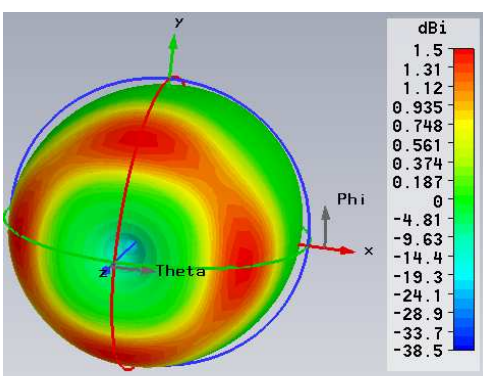

Figure 4: Gain plot of CDRA at 3.2 GHz.

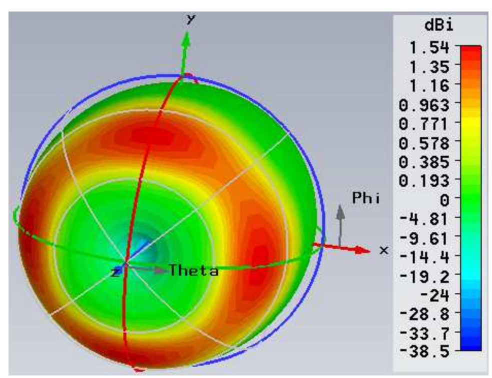

Figure 5: Gain plot of HDRA at 3.2 GHz.

Table 1: Comparison of the proposed structure.

Rudimentary Geometries	**Rectangular**	**Cylindrical**	**Hemispherical**
Dimensions (mm)	$a = b = 30$, $d = 15$	$r = 18$, $h = 15$	$hr = 18.61$
Resonant Frequency	3.2 GHz	3.2 GHz	3.3 GHz
Bandwidth Range	2.9–4.7 GHz	2.9–4.5 GHz	3–4.5 GHz
Bandwidth ($S_{11} < -10\,\text{dB}$)	56%	50%	46%
Total Peak Gain	1.56 dBi	1.50 dBi	1.54 dBi

Table 1 summarize the all numerical results for different geometries of DRA. It can be seen that the impedance bandwidth (for return loss below $-10\,\mathrm{dB}$) of the DRA is 56%, 46% and 50% for rectangular, hemispherical and cylindrical respectively. It can be observed that the rectangular antenna not only achieves wider bandwidth, but also its gain is considerably higher than other DRAs.

4. CONCLUSION

In this paper comparative study of different rudimentary geometries of DRAs design has been carried out. The rudimentary geometries of DRA were rectangular, cylindrical and hemispherical, which are used for investigation of DRA performance. These rudimentary geometries of DRA give a better understanding of design parameters of an antenna and their effect on return losses, impedance bandwidth, gain, and resonant frequency. It was found that the rectangular DRA fed by coaxial probe provide better gain radiation pattern as compared to other geometries.

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