Theoretical and Experimental Investigation of Probe-fed Rectangular Dielectric Resonator Antennas

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INTRODUCTION

Dielectric Resonators (DRs) are widely used in shielded microwave circuits such as filters and oscillators. In recent years, they have been studied extensively as antennas [1-5], as they could offer a number of advantages over other types of antennas including small size, large bandwidth, simple coupling structure and high radiation efficiency. Dielectric resonators have been studied in the literature in hemispherical, cylindrical, cylindrical ring and rectangular geometry. Compared with other geometry's, rectangular resonators have some advantages in fabrication process, and electrically they have two independent aspect ratios, which could be chosen to provide the required radiation patterns, gain, resonance frequency, input impedance and bandwidth.

In this study a rectangular dielectric resonator antenna (RDRA), excited by a small probe residing on an infinite ground plane, is investigated theoretically and experimentally. Two different modelling techniques, namely the Conventional Dielectric Wave-guide Model (CDWM) and the Finite Element Method (FEM) are employed for the prediction of the resonance frequency, radiation patterns, directivity, *Q*-factor, input impedance and bandwidth of the antenna. The theoretical results are verified experimentally revealing the merits of each theoretical modelling.

THE CONVENTIONAL DIELECTRIC WAVE-GUIDE MODEL (CDWM)

Fig.1 illustrates the antenna under consideration. The length, width and height of the resonator are a, b and h respectively and is located on the top of a circular ground plane with diameter d. A vertically oriented coaxial probe of height h located at $x=a/2$ and $\varphi=0°$ excites the lowest mode of the resonator which is TE^{y}_{111} [6]. Image theory can be applied to replace the ground plane with a portion of the resonator extending to $z=-h$. Based on the CDWM theory, the RDR is assumed to be the truncation of a long dielectric wave-guide, so their characteristic equations are similar. By solving Maxwell's equations, the fields of the dominant mode are determined, while the boundary conditions are four perfect magnetic walls (PMW) at $x=\pm a/2$and $z=\pm h$ and the tangential fields on the two other surfaces are continuos. As a result the characteristic equations for the RDR are:

$$k_x = (\pi / a), k_z = (\pi / 2h),\ k_y \tan(k_y b / 2) = \sqrt{k_x^2 + k_z^2 - k_0^2} \qquad (1)$$

The resonance frequency is the solution of the separation function using the relative effective dielectric constant (EDC) [7,8] concept given by:

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_e k_0^2 \qquad (2)$$

where k_0 is the free space wave number and $\varepsilon_e = \varepsilon_r - (k_y / k_z)^2$.

The radiated fields are considered to be due to the equivalent magnetic currents on the surfaces of the resonator, which are calculated by the fields that exist in the resonator. In far field region $E_r \approx 0$and the antenna directivity D at $\theta=0°$can then be calculated using E_θ and E_φ.

THE FINITE ELEMENT MODEL

The RDR antenna is simulated using HP85180A High Frequency Structure Simulator (HFSS). The HFSS is a software package for computing the S-parameters of passive, high frequency structures at the defined ports that are

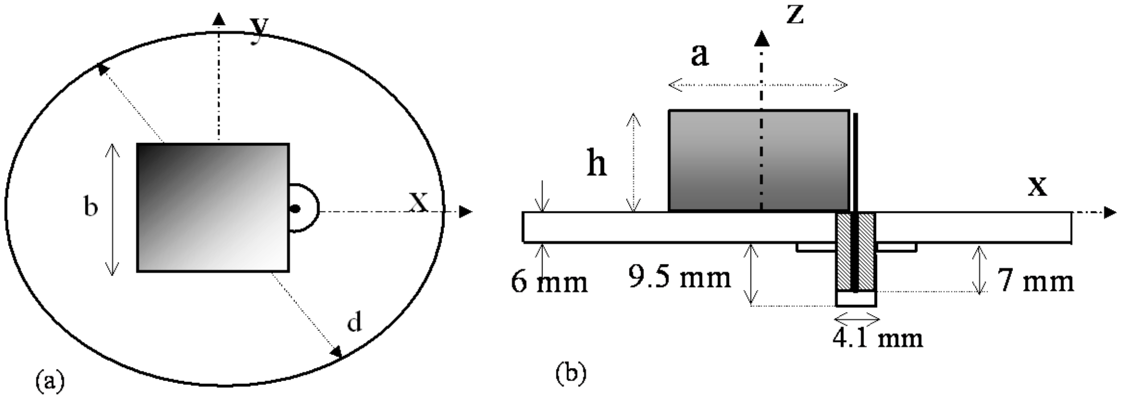

Fig. 1: The structure of the antenna: a) Top View b) Side view

supported by a transmission line having the same cross section as the port. The simulation technique that is used to calculate the full 3-D electromagnetic fields inside and outside (far-field radiation patterns) is based on the FEM. In general, in the HFSS the geometric model is divided into a large number of elements, which are thetrahedra, and all these elements together are refereed to the finite element mesh. The value of a vector field quantity such as *E*- or *H*-field inside the each element is interpolated from the vertices of the tetrahedron.

Antenna structures can be analysed on the HFSS by defining a surface, which totally surrounds the antenna as an absorber boundary. This surface, which represents as an open space, is allowed to radiate the waves instead of being contained within. At this radiation surface, the second order radiation boundary condition is employed [9]:

$$(\nabla \times \overline{E})_{\tan} = jk_0 \overline{E}_{\tan} - (j/k_0)\nabla_{\tan} \times (\nabla_{\tan} \times \overline{E}_{\tan}) + (j/k_0)\nabla_{\tan}(\nabla_{\tan} \cdot \overline{E}_{\tan}) \qquad (3)$$

where $\overline{E}_{\tan}$ is the component of the E-field that is tangential to the surface. The radiation surface does not have to be spherical, the only restrictions regarding their shape is that they have to be convex with regard to the radiation source and to ensure accurate results, it should be applied at least a quarter of wavelength away from the source of the signal.

The HFSS maps the *E*-field computed in (3) on the absorber surface and then calculates the far-field and radiation patterns using

$$\overline{E}(x,y,z) = \int_s \left[(j\omega\mu_0 \overline{H}_{\tan})G + (\overline{E}_{\tan} \times \nabla G) + (\overline{E}_{normal} \times \nabla G) \right] ds \qquad (4)$$

where $\overline{E}_{\tan}, \overline{H}_{\tan}$ are the tangential components of electric and magnetic fields respectively and $\overline{E}_{normal}$ is the normal component of the electric field on the radiation surface s, and *G* is the free space Green's Function. The structure that is used to simulate the RDRA is shown in Fig. 2, which is a simple structure to reduce the required computation time.

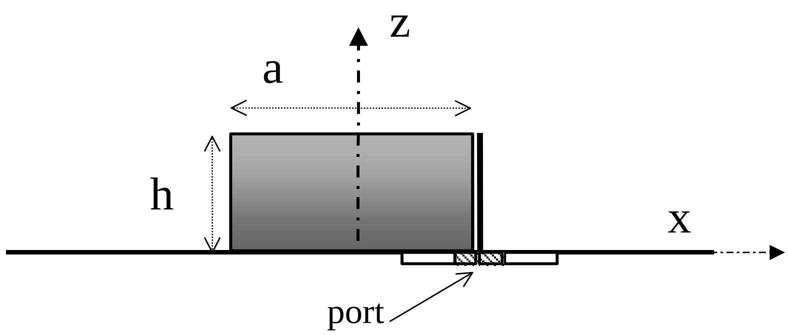

Fig. 2 The structure of the antenna for FEM simulation

MEASUREMENT

To confirm the results from the CDWM and FEM, an experimental study was carried out using the RDR with dimensions *19, 19* and *9.5mm* in x-, y- and z-direction respectively and $\varepsilon_r=38$ on a ground plane with $d=10cm$. A coaxial probe whose length h was equal to the height of the resonator excited the TE_{111} mode of the operation. The resonance frequency and return loss was measured with the use of the HP8510 network analyzer. Q-factor of the antenna was calculated from the return loss versus frequency plot using one-port measurement technique [10]. The radiation patterns of E_θ at $\varphi=0°$ and E_φ at $\varphi=90°$ and the gain of the antenna were measured by using a calibrated dipole antenna placed *120cm* away from the antenna inside the anechoic chamber. All the theoretical and experimental results are summarized in Table 1 and the radiation patterns are shown in Fig. 3. It can be seen that the simulation can produce accurate results of the radiation patterns. But only, there is a difference in simulated and measured E-Plane radiation patterns compare with CDWM at small elevation angles due to the effect of the finite size of the ground plane.

Table 1. Radiation characteristics of the RDRA on a circular ground plane

Parameter:	**CDWM** Infinite ground plane	**FEM** Finite ground plane *d=10cm*	**Measured** Finite ground plane *d=10cm*
Frequency (GHz)	2.212	2.078	2.206
Return Loss (dB)	—	23.247	20.585
Q-Factor	33.088	36.793	30.906
Bandwidth (VSWR<2.5) (%)	2.85	2.578	3.075
Directivity	2.881	4.629	—
Gain	—	—	3.344

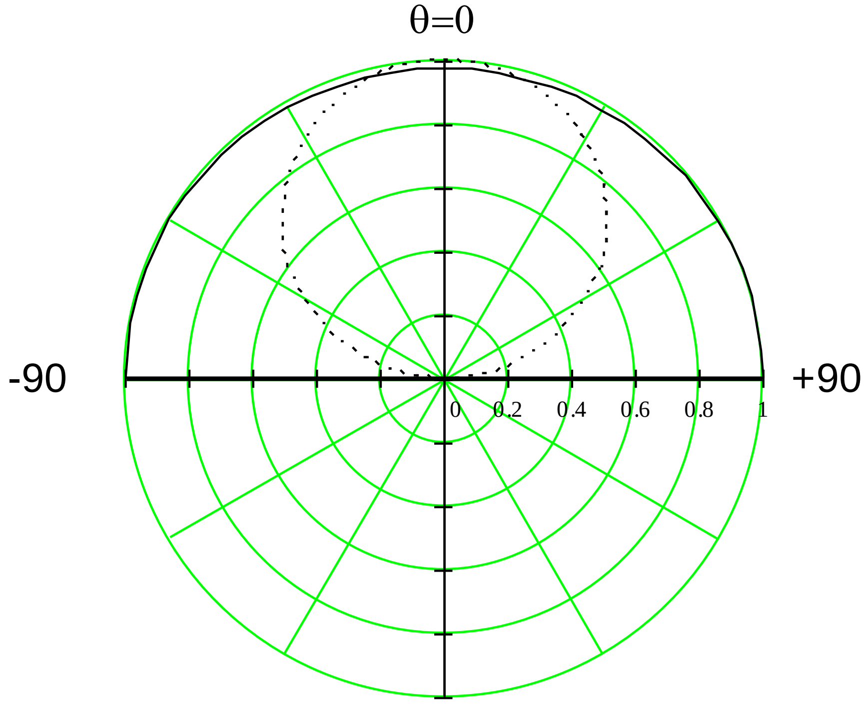

Fig. 3-a: Theoretical Radiation Patterns based on CDWM and an infinite ground plane

E_θ at $\varphi=0°$ ———— E_φ at $\varphi=90°$ ....

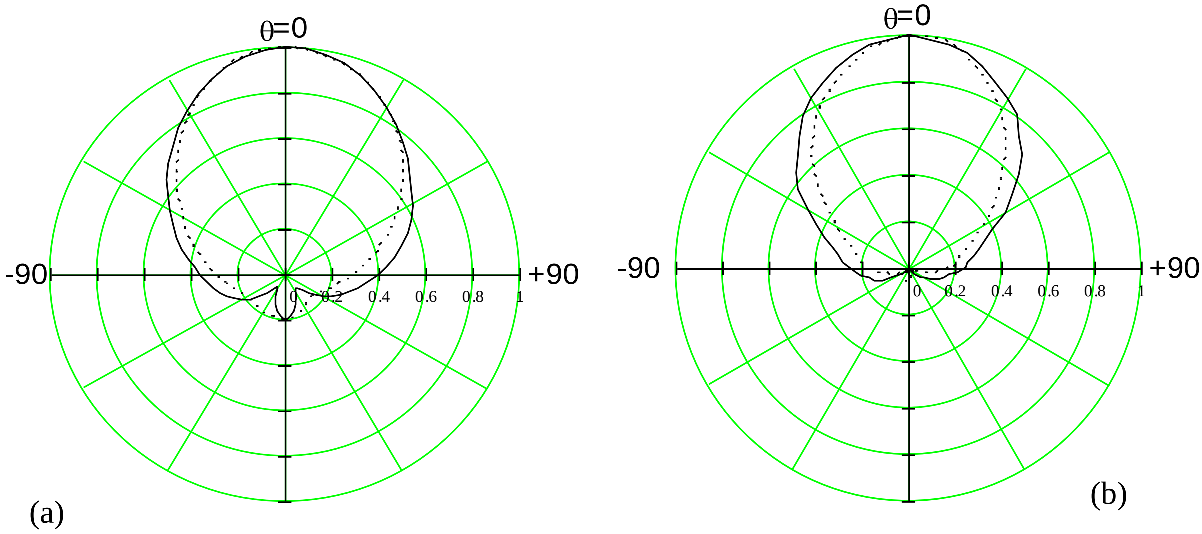

Figure 3-b Radiation Patterns of the RDRA on a circular ground plane with *d=10cm*
a) Simulated (FEM) b)Measured
E_θ at $\varphi=0°$ ———— E_φ at $\varphi=90°$ ....

CONCLUSIONS

Two different modeling methods are presented for the analysis of a rectangular DRA. Results indicate both the CDWM and the HFSS can produce a good estimation of the antenna characteristics. However, the effect of the size of the ground plane needs to be taken into consideration in the modeling, so as to produce accurate prediction of radiation patterns, in which case the CDWM has its limitation.

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