THEORETICAL & EXPERIMENTAL INVESTIGATION OF THE INPUT IMPEDANCE OF PROBE-FED RECTANGULAR DIELECTRIC RESONATOR ANTENNA

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Abstract: An analysis of the input impedance of a Rectangular Dielectric Resonators Antenna (RDRA) operated at the dominant mode TE_{111} is presented. The effects of the probe length and its position with respect to the resonator on the resonance frequency and the input impedance of the antenna are investigated. The antenna structure is numerically simulated using the High Frequency Structure Simulator (HFSS) software package based on the Finite Element Method (FEM). A few experimental set-ups were examined and resonance frequency and input impedance were measured. The results show good agreement between theory and experiments and also the significance of the distance between the resonator and feed probe in simulation.

1. Introduction

Dielectric Resonators (DRs) are widely used in shielded microwave circuits such as filters and oscillators. In the recent years, the study of using open DRs as antenna has grown due to offering advantages including small size, light in weight, large bandwidth, simple feed structure and high radiation efficiency over conventional types of antennas [1-6]. Dielectric resonators have been studied in the literature in hemispherical, cylindrical, cylindrical ring and rectangular geometry. Compared with the other geometry's, RDRs [5,6] have a few 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.

Input impedance of a Cylindrical Dielectric Resonator Antenna (CDRA) has been computed numerically using the Method of Moments (MoM) [7] and the Finite Difference Time Domain (FD-TD) [8,9].

In this paper the FEM is applied to analyse the impedance of a probe-fed RDRA operating at the fundamental mode TE^{y}_{111} [6] located on a circular ground plane. The effect of the probe length and its position with respect to the resonator on the input impedance of the antenna is studied.

2. Antenna Structure

The structure of the probe-fed RDRA under investigation is shown in Figure 1. It consists of a dielectric resonator with dimensions 19×19×9.5mm^3 and dielectric constant ε_r=38 located on a 100mm diameter circular plane as the ground and the supporter of the antenna as well. A SMA connector excites the resonator, where the internal conductor is the probe with length L and the distance between probe and the DR is s.

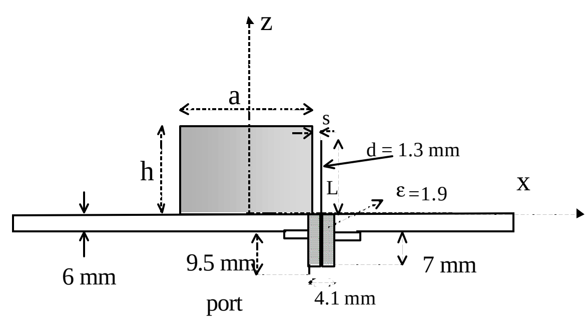


Figure 1: The RDRA structure under investigation

3. Antenna Simulation

The antenna structure is simulated using the HP85180A High Frequency Structure Simulator (HFSS) [10], which is a software package to calculate S-parameters of the high frequency structure such as transmission lines and antennas. The simulation technique is based on the FEM calculate the full 3-D electromagnetic fields inside and outside (far field) the structure. In general, in the HFSS the geometric model is automatically divided into a large number of elements, called thetrahedra, and all these elements together are refereed to the finite element mesh. The fields in each element are represented by a local function. The value of a vector field quantity, E- or H-field, at a point inside the element is obtained using interpolation based on the value at the vertices of the each element.

Antenna structures can be analysed using the HFSS by defining a surface, which totally surrounds the structure as an absorber boundary. This surface represents as an open space and is allowed to radiate the waves instead of being contained within. On the radiation surface, the second order radiation boundary condition is employed that is [10]:

$$(\nabla\times\overline{E})_{\tan} = jk_0\overline{E}_{\tan} - (j/k_0)\nabla_{\tan}\times(\nabla_{\tan}\times\overline{E}_{\tan}) + (j/k_0)\nabla_{\tan}(\nabla_{\tan}\cdot\overline{E}_{\tan}) \qquad (1)$$

where $\overline{\mathrm{E}}_{\tan}$ is the tangential component of E-field on the boundary. The radiation surface does not have to be spherical, the only restrictions regarding to 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 Equation (1) on the absorber surface and then calculates the radiation fields using:

$$\overline{E}(x,y,z) = \int_s \begin{bmatrix} (jwm_0\overline{H}_{\tan})G + \\ (\overline{E}_{\tan}\times\nabla G) + (\overline{E}_{normal}\times\nabla G) \end{bmatrix} ds \qquad (2)$$

where $\overline{\mathrm{E}}_{\tan}, \overline{\mathrm{H}}_{\tan}$ are the tangential components of electric and magnetic fields respectively and $\overline{\mathrm{E}}_{\mathrm{normal}}$ is the normal component of the electric field on the radiation surface *s*, and G is the free space Green's function.

4. Results & Discussion

First, the probe-fed RDRA was simulated for different probe length, while the probe spacing was set to zero. Figure 2–a shows the variation of the input resistance and reactance against frequency for different probe length.

It can be seen that the TE^{y}_{111} mode is strongly excited when the normalised probe length is greater than 0.5. The input impedance increased with the length of the probe but the resonance frequency decreases. Figure 2-b shows the input impedance at the resonance frequency including the resonance frequency, where S_{11} is minimum. It can be seen that best matching point to 50Ω is obtained at the normalised probe length of L/h=o.7. The probe length thus is a key parameter for adjustment of matching condition.

To study the effect of the probe position on the input impedance of the RDRA a few simulations was carried out, while the distance between the resonator and the probe was changed from 0 to 2mm. Simulated results for the case of L/h=1 is shown in Figure 3 versus probe spacing. It shows that introducing a very small space between the resonator and feed probe, the input resistance drops from 93.5Ω to 50Ω. The input reactance changes from inductive to a capacitive load when s is greater than 0.035mm. It is important that to note that for small values of s, the resonance frequency does not change. It is believed that a small space between objects make better mesh generation in the HFSS software and so more accurate results can be obtained [11,12].

To verify the simulated results a few experiments have been carried out. The measured input impedance versus frequency for different probe length is shown in Figure 5. It can be seen that the mode of interest is strongly excited for L/h≥0.5. For normalised probe length equal and less than 0.53 the input impedance is capacitive in all the band which means undercoupling conditions of the resonator. The measured input resistance and reactance of the RDRA at the resonance frequency is shown in Figure 5-b. It can be seen that the antenna is better matched at normalised probe length of L/h=0.85.

The measured input reflection coefficient response in the range of 1.9GHz – 2.5GHz for various probe lengths are shown on smith chart in Figures 5a-5d together with the simulation results. Apart from difference in the resonance frequency, the simulated results agree well with those obtained from experiments. It is said that difference in resonance frequency is due to the other imperfection fabrication such as gap between resonator and ground plane [12]. It can be seen that the trace of S_{11} representing the input impedance of an RLC resonance circuit. By decreasing the probe length, the radius of the circle is decreased shows that the Q_0 of the antenna is increased and as a result the bandwidth of the RDRA is decreased.

5. Conclusion

The resonance frequency and input impedance characteristics of a RDRA in terms of the probe length and its position with respect to the resonator have been considered. The HFSS software package was used to simulate antenna based on the FEM.

It was concluded that the mode of interest, TE^{y}_{111}, is strongly excited for normalised probe length of L/h≥0.5. The predicted input impedance of the RDRA agrees reasonably well with that obtained experimentally for different normalised probe length. The agreement could however be improved when a small gaps (probe spacing) between the resonator and feed probe of s=0.035 mm is introduced in simulation. This confirms the importance of the fabrication imperfection, which is needed to consider in simulation.

The probe length is an important factor to adjust matching condition of the antenna. The measured results of the input impedance show that the antenna is better matched at normalised probe length of 0.86. The simulated results, however, show that the optimum normalised probe length should be 0.7.

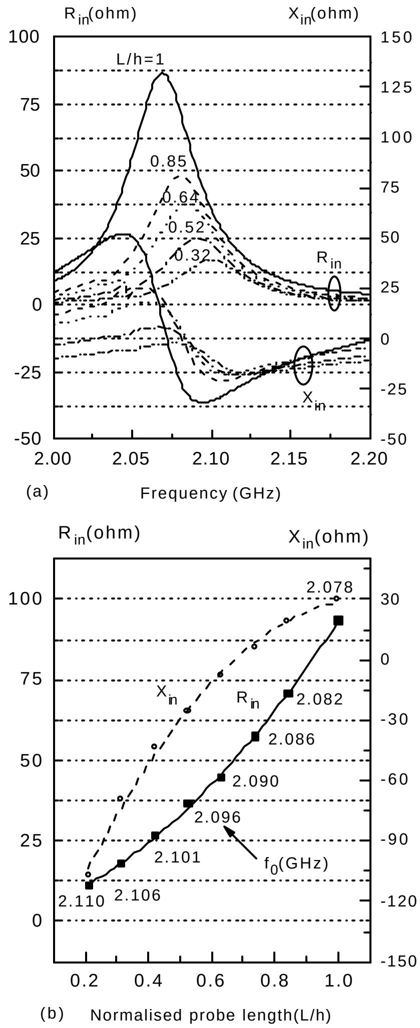


Figure 2: Simulated results of input impedance of the RDRA for s=0: a) input impedance versus frequency, b) impedance at the resonance and the resonance frequency

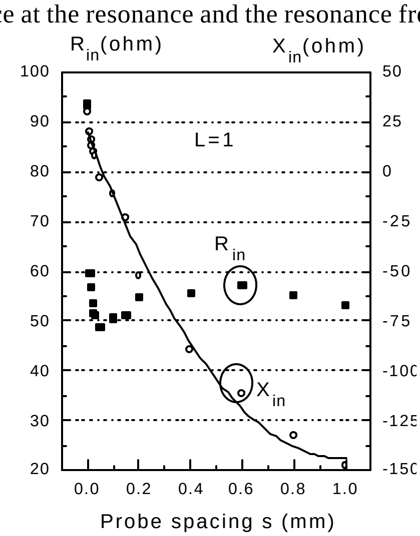


Figure 3: Simulated results of the input impedance versus probe spacing s.

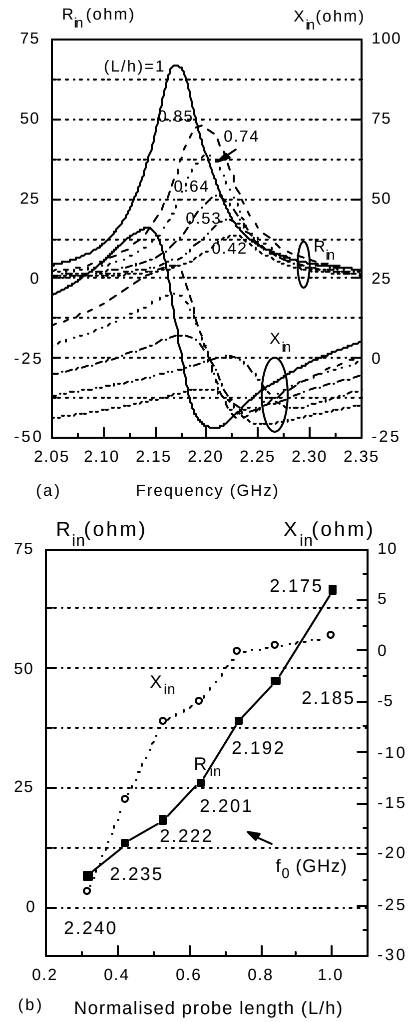


Figure 4: Experimental results of impedance of a RDRA: a) input impedance against frequency, b) input resistance and reactance at the resonance frequency

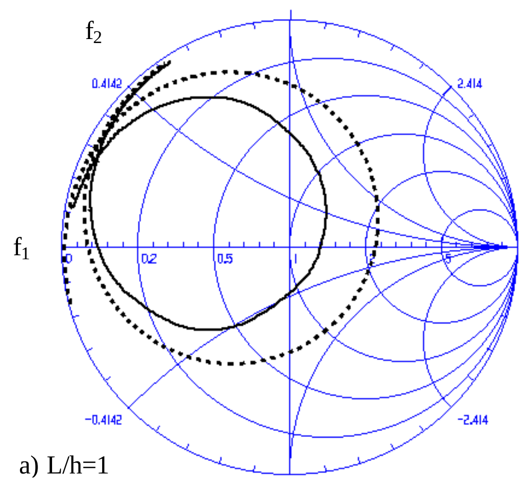
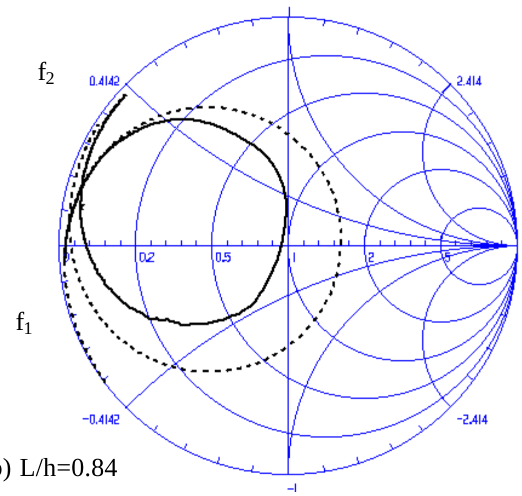
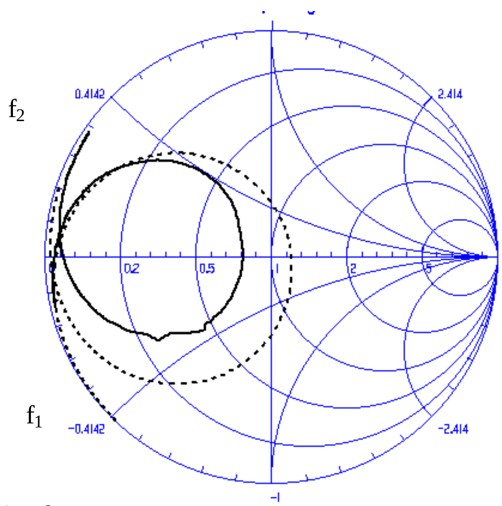


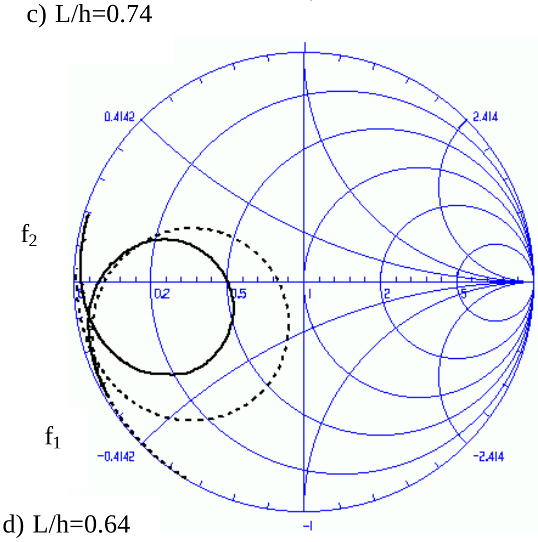
Figure 5-a: The measured and simulated reflection coefficient against frequency for (L/h=1). [Continue next page].



b) L/h=0.84



c) L/h=0.74



d) L/h=0.64

-------- Simulation: (f1=1.9 GHz, f2=2.3 GHz),
———— Measurement: (f1=2.1 GHz, f2=2.5 GHz)

Figure 5b- 5d: The measured and simulated reflection coefficient against frequency for different normalised probe length.

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