NUEMERICAL MODELLING AND EXPERIMENTAL STUDY OF MICROSTRIP-SLOT COUPLED RECTANGULAR DIELECTRIC RESONATOR ANTENNA

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ABSTRACT

A Microstrip-Slot Coupled Rectangular Dielectric Resonator Antenna (RDRA) operated at dominant TE^{y}_{111}mode of operation is investigated numerically and experimentally. The effect of slot size on the radiation characteristics of the RDRA is studied. The antenna structure is simulated using the High Frequency Structure Simulator (HFSS) software package. A few experimental set-ups were examined and the antenna parameters were measured. The simulated results are presented and compared with those obtained by experiments. It is shown that the size of the slot can significantly affect the radiation properties of the RDRA and there are good agreements between numerical and experimental results.

Keywords: Dielectric Resonator, Antennas, Finite Element Method and Microstrip-Slot Coupling

1- Introduction

Dielectric Resonators (DRs) in cylindrical, rectangular and other geometries placed on top of a ground plane could operate as an efficient antenna and have received increased interest in recent years for their potential applications in microwave and millimetre wave communication systems. They have been widely used as a tuning component in shielded microwave circuits such as filters, oscillators and cavity resonator [1-6]. They can be fed using different feed arrangements including an axial probe, microstrip transmission line, microstrip-slot and co-planner waveguide.

The slot or aperture-coupling scheme was fist introduced by Pozar [7] for microstrip antennas. This type of feeding, then, was used by Martin [8] for a cylindrical DRA. In 1994 Shum [9] numerically analysed a slot coupled RDRA using Finite Difference Time Domain (FD-TD) and return loss was calculated and compared with experimental result. Theoretical analysis of a microstrip-slot coupled RDRA based on the modal expansions and the spectral domain approach was developed by Antar [10]. Yau [11] also reported a rigorous numerical study based on the Method of Moments (MoM).

In this study a microstrip-slot coupled RDRA operating at fundamental TE^{y}_{111} mode is investigated numerically using the Finite Element Method (FEM) and the results are compared with those obtained by experiments.

2- Antenna Structure

The structure of the RDRA under investigation is shown in Figure 1. It consists of a dielectric resonator with dimensions $19\times19\times9.5mm^3$ and dielectric constant $\varepsilon_r=38$ which is located on the ground plane of a microstrip line and feed through a non-resonant narrow slot. The slot of length L_a and width W_a is etched on the ground plane of the microstrip line. The open stub at the end of the line is $L_s=22mm$ long, which is nearly $\lambda_g/4$ where the magnetic field is maximum, from the centre of the slot. The feed line is etched on the bottom side of a piece of RT / Duriod 5880 with dimensions 90mm (length), 80mm (width), 0.787mm (thickness), relative dielectric constant of 2.2 and copper thickness of 35µm. The line is 63mm long and 2.45mm wide giving a characteristic impedance of 50Ω.

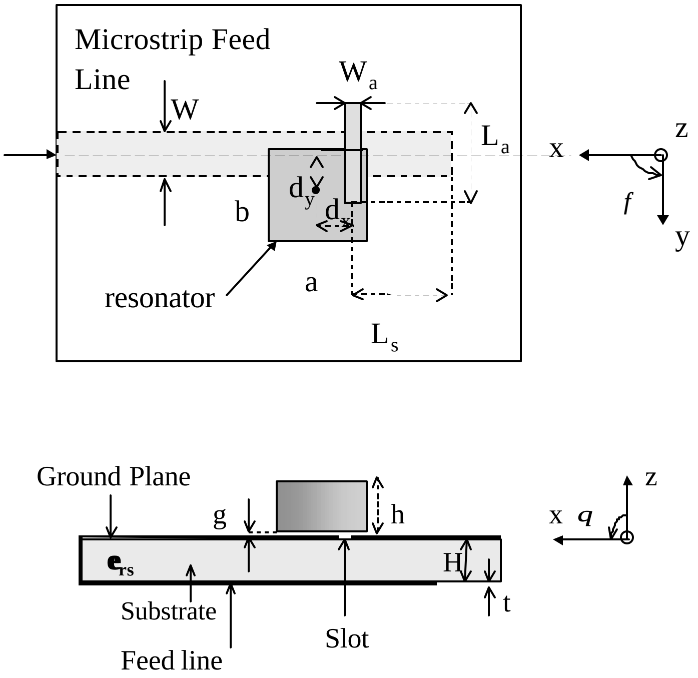

Figure 1: The microstrip-slot coupled RDRA structure

3- Antenna Simulation

The antenna structure is simulated using the HP85180A High Frequency Structure Simulator (HFSS), 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) of 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 [13]:

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

where $\overline{E}_{tan}$ 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:

$$\overline{E}(x,y,z) = \int_s \begin{bmatrix} (j\omega\mu_0\overline{H}_{tan})G + \\ (\overline{E}_{tan}\times\nabla G) + (\overline{E}_{normal}\times\nabla G) \end{bmatrix} ds \qquad (2)$$

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.

4- Numerical Results

The effect of the slot size on the radiation performance of the antenna is studied first. The resonator is placed on a non-resonant coupling slot where $d_x=d_y=0$, which makes a symmetrical coupling between the resonator and the slot. The slot length L_a is varied from 6mm to 14mm and its width W_a is varied between 0.2mm to 1.8mm.

The simulated results for reflection coefficient S_{11} versus slot length for different values of W_a are shown in Figure 2-a. It can be observed for each slot width, there is an optimum length for critical coupling. The optimum slot length decreases as the slot width is increased. For the considered range of slot size, the reflection coefficient varies between ~ –0.5dB and ~–32dB. For slot width $W_a \geq 1$mm, the maximum coupling occurs at the slot length of 9mm. Therefore, the optimum coupling can be obtained by adjusting the slot size.

The simulated result of the resonance frequency versus slot length for different values of width are shown in Figure 2-b together with fitted curves using Microcal Origin software. It can be seen that increasing the slot width or length result in the resonance frequency to decrease.

The simulated radiation patterns of the microstrip-slot coupled RDRA shows that the patterns are not much affected by the size of the slot. However, as shown in Figure 3-a and b for L_a=9mm, the radiation patterns are generally symmetric, but for the other values of L_a, they are slightly deformed due to the under-coupling or over-coupling of the resonator.

5- Experimental Results

Figure 4 shows the variation of the measured return loss and resonance frequency of the RDRA versus slot length and different value of the sloth width. It can be seen there is an optimum slot length for best coupling for each value of width. The measured radiation patterns are shown in Figure 5 and which shows that patterns are not sensitive to the slot area.

The experimental results together with the predicted values in case of best matching point at W_a=1.4mm, L_a=9mm are summarized in Table 1. The resonance frequency differs by only ~7%, which is believed to be due to fabrication imperfection such as gap due to surface roughness between the slot and resonator.

6- Discussion and Conclusions

The microstrip-slot coupled RDRA was analyzed using FEM. Results indicate that the numerical method predicts very well the radiation patterns of the antenna and these are not affected by the size of the slot. There is an error in the simulated resonance frequency and bandwidth of the RDRA in compare to the measurement values. The resonance frequency differs only by ~7%, while BW differs 20%. This is believed to be due to fabrication imperfection such as air gap between the slot and resonator in the antenna structures that is needed to be taken into consideration in numerical modeling to produce more accurate prediction of antenna parameters.

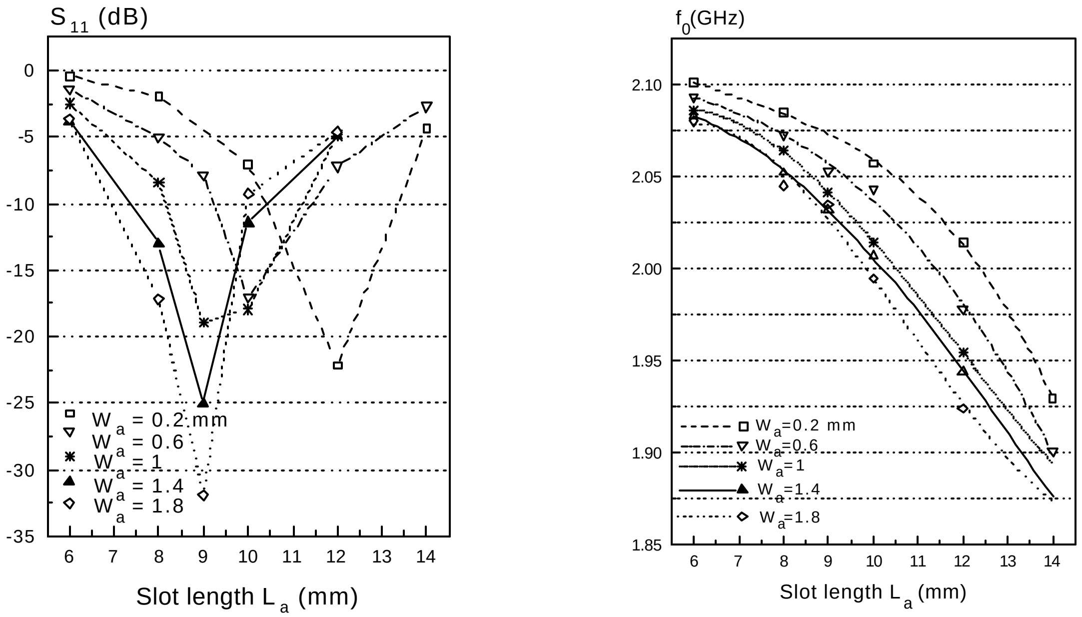

Figure 2: Simulated reflection coefficient and resonance frequency of the microstrip-slot coupled RDRA versus slot length and different value of width.

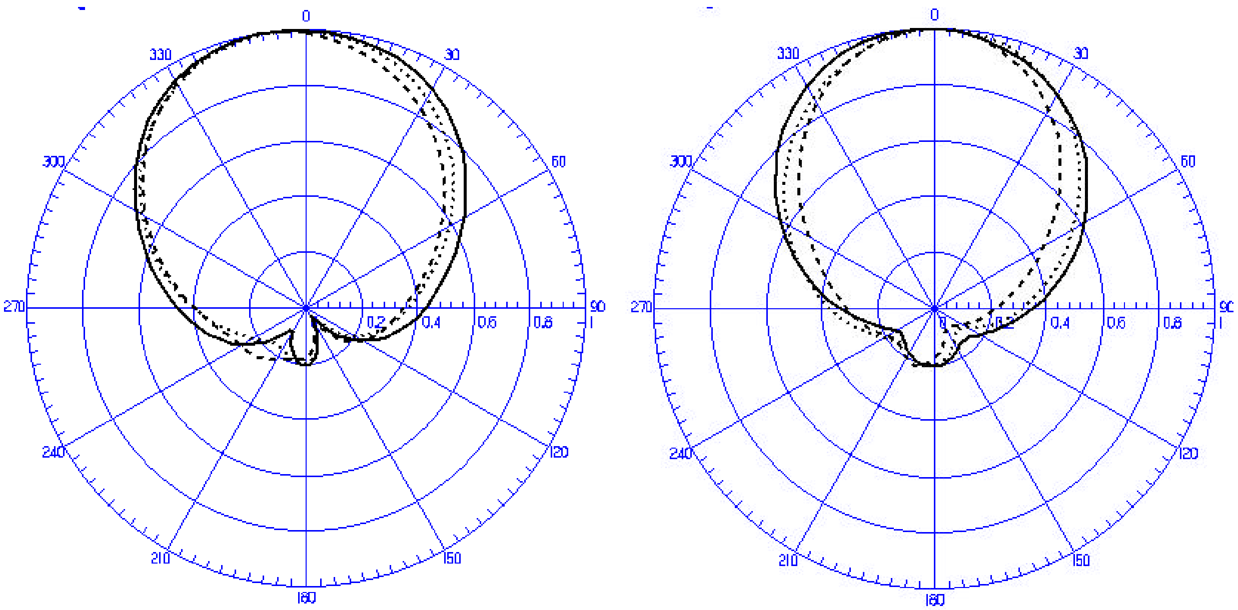

Figure 3: Simulated radiation patterns of the microstrip-slot coupled RDRA for W_a=1.4 mm and different length.

(L_a= 6 mm ·················· L_a= 9 mm ———— L_a=12 mm ------)

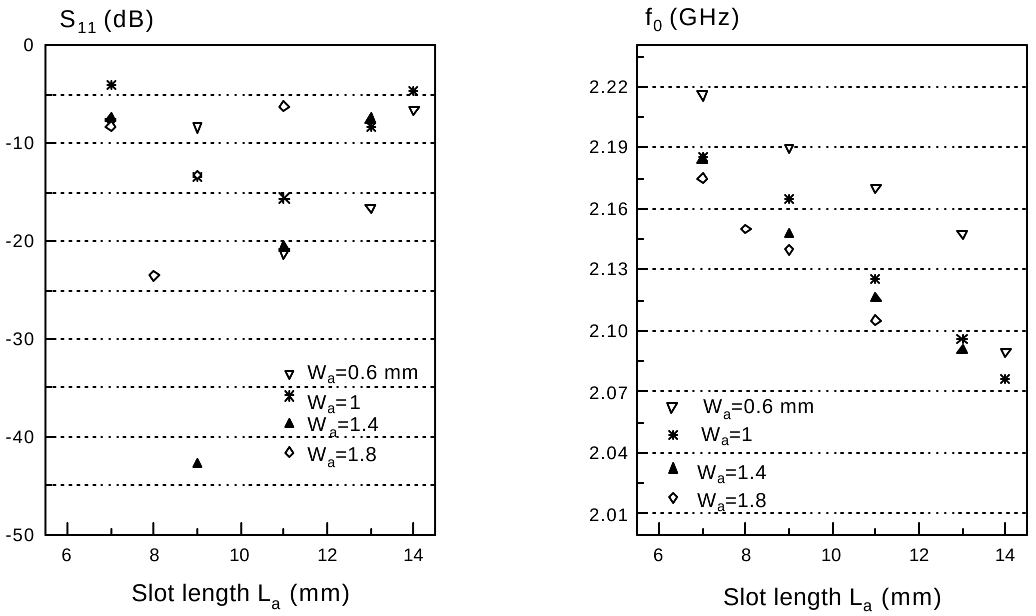

Figure 4: The measured resonance frequency and reflection coefficient of the microstrip-slot coupled RDRA versus slot length and different slot widths.

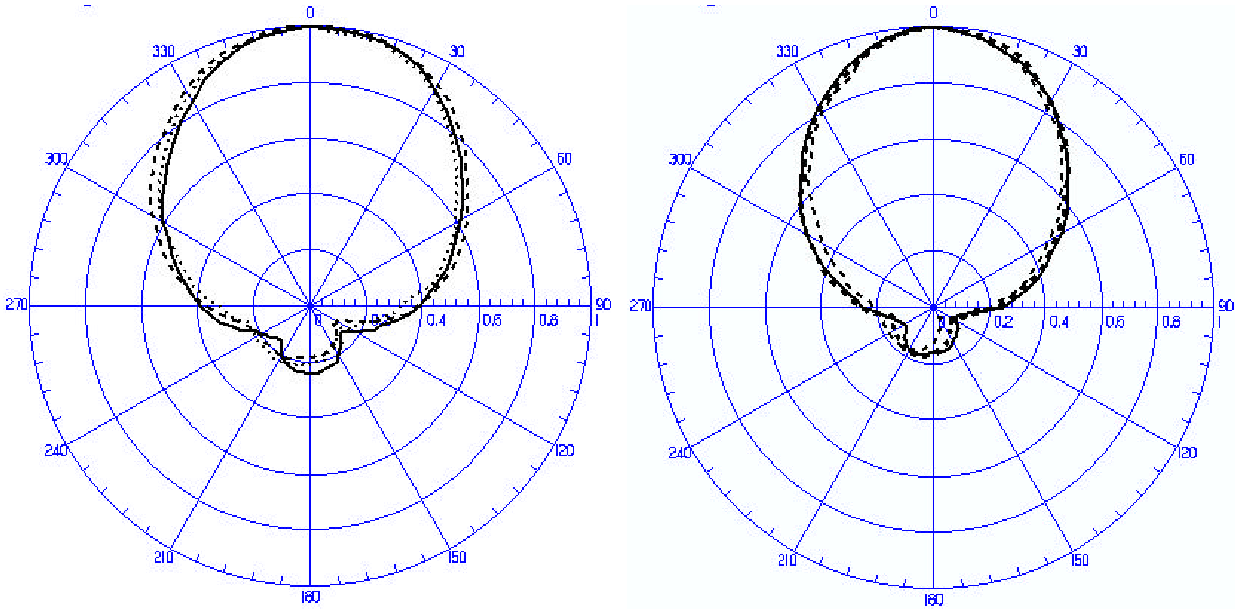

Figure 5: The measured radiation patterns of the microstrip slot-coupled RDRA for W_a=1.4 mm and different slot length.

(L_a=7 mm …………… L_a=9 mm ——— L_a=11 mm -------)

Table 1. The simulated and measured results of the microstrip-slot coupled RDRA at the best coupling condition for W_a=1.4mm, L_a=9mm.

	Simulation	**Measurement**
f_0 (GHz)	2.032	2.147
Return loss (dB)	25.064	42.877
Coupling Coefficient b	1.118	1.014
BW (%) VSWR≤2.6	2.25	2.7
Directivity, Gain	3.54	3.02

7- References:

[1]. McAllister, M.W., Long, S.A. and Conway, G.L., "Rectangular dielectric resonator antenna", Electron. Lett. , 1998, 19, pp. 218-219.

[2]. Kajfez D. & Guillon P., "Dielectric resonators ", Artech House, Norwood, MA, 1986.

[3]. Mongia, R.K., "Theoretical and experimental resonance frequencies of rectangular dielectric resonators ", IEE Proceedings-H, 1992, 139, pp. 98-104.

[4]. Mongia, R. K. and Bharita, "Dielectric resonator antenna- A review and general design relations to resonant frequency and bandwidth ", International Journal of Microwave & Millimetre-Wave Computer Aided Engineering, Vol. 4, 1994, pp. 230-247.

[5]. Mongia, R.K. and Ittipiboon, A., "Theoretical and experimental investigations on rectangular dielectric resonator antennas ", IEEE Trans., 1997, AP-45, 1997, pp. 1348-1356.

[6]. Neshati M. H. and Wu, Z., "Probe-Fed Rectangular Dielectric Resonator Antennas: Theoretical Modeling & Experiments. " , 10th Iranian Conference on Electrical Engineering, May 14-16, 2002, Tabriz University, Tabriz, Iran, Communication Proceedings Vol. 2 pp. 573-579.

[7]. Pozar D. M., "A Reciprocity Method of Analysis for Printed Slot and Slot-Coupled Microstrip Antenna", IEEE Transactions on Antennas and Propagation, 1986, Vol. AP-34, No. 12, pp. 1439-1446.

[8]. Martin J. T. H. S., Antar Y. M. M., Kishk A. A., Ittipiboon A. and Cuhaci M., " Dielectric Resonator Antenna Using Aperture Coupling ", Electronics Letters, 1990, Vol. 26, pp. 2015-2016.

[9]. Shum S. M. and Luk K. M., "Analysis of aperture coupled Rectangular Dielectric Resonator Antenna ", Electronics Letters, 1994, Vol. 30, pp. 1726-1727.

[10]. Antar Y. M. M. and Fan Z., "Characteristics of Aperture-Coupled Rectangular Dielectric Resonator Antenna ", Electronics Letters, 1995, Vol. 31, pp. 1209-1210.

[11]. Antar Y. M. and Fan, Z., "Theoretical Investigation of Aperture-Coupled Rectangular Dielectric Resonator Antenna ", IEE Proceedings on Microwave Antennas Propagation, 1996, Vol. 143, pp. 113-118.

[12]. Yau, D. and Shuley, N. V., "Numerical Analysis of an aperture coupled rectangular dielectric resonator antenna using surface formulation and method of moments.", IEE proceedings of Microwave & Antenna Propagation, 1999, Vol.146, pp. 105-110.

[13]. Hewlett-Packard, "HP85180A High Frequency Structure Simulator. User's Reference", 1994.