MICROSTRIP-SLOT COUPLED RECTANGULAR DIELECTRIC RESONATOR ANTENNA: THEORETICAL MODELLING & EXPERIMENTS

M. H. Neshati* **and Z. Wu****

*: Electrical Dept. Sistan & Baluchestan University. Zahedan, 98164, Iran.
**: Electrical & Electronics Engineering Dept., UMIST, Manchester M60 1QD, UK.
e-mail: neshat@hamoon.usb.ac.ir

ABSTRACT

A microstrip-slot coupled Rectangular Dielectric Resonator Antenna (RDRA) operated at the fundamental mode is investigated numerically and experimentally. The effect of slot size on the radiation performance of the RDRA is studied. The antenna structure is simulated using the High Frequency Structure Simulator (HFSS) software package. 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.

1. Introduction

Dielectric Resonators have received great 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 resonators. With an appropriate feed arrangement, they can also be used as antennas, and they offer efficient radiation [1-6]. Dielectric resonator antennas (DRAs) in cylindrical, rectangular, and hemispherical shaped and other geometries have been reported in the literature. They can be fed using different feed arrangements including a coaxial probe, microstrip transmission line, microstrip-slot and co-planner waveguide.

The slot-coupling scheme was introduced by Pozar [7] for patch antennas and it was used by Martin [8] for a cylindrical DRA. Then, Shum [9] numerically analyzed a slot coupled RDRA using FD-TD and return loss was calculated and compared with experiments. Theoretical analysis of a microstrip-slot coupled RDRA based on the modal expansions and spectral domain approach was presented by Antar [10,11]. Yau [12] also reported a rigorous numerical study using the Method of Moments (MOM) for this type of antenna.

In this paper a microstrip-slot coupled RDRA operating at TE_{111} mode is studied numerically using the Finite Element Method (FEM) and investigated experimentally.

2. Antenna Structure

The structure of the RDRA under investigation is shown in Figure 1. The RDRA of dimensions $19\times19\times9.5\text{mm}^3$ and dielectric constant ε_r=38 is located on a ground plane of a microstrip line and is fed 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, which is approximately $\lambda_g/4$ long. The feed line is etched on the bottom side of a RT / Duriod 5880 PCB 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.

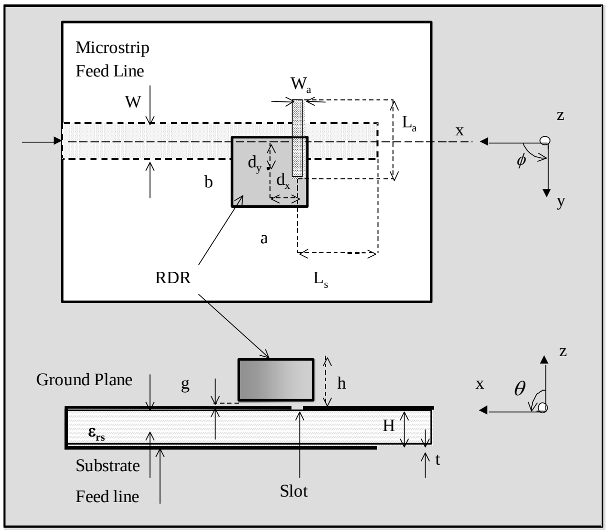

Figure 1: The microstrip-slot coupled RDRA structure

3. Antenna Simulation

The antenna structure is simulated using the HP85180A High Frequency Structure Simulator (HFSS). The simulation technique is based on the FEM and it calculates 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, or 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 the antenna structure and 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]:

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

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:

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

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

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 the width W_a is varied between 0.2mm to 1.8mm.

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

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

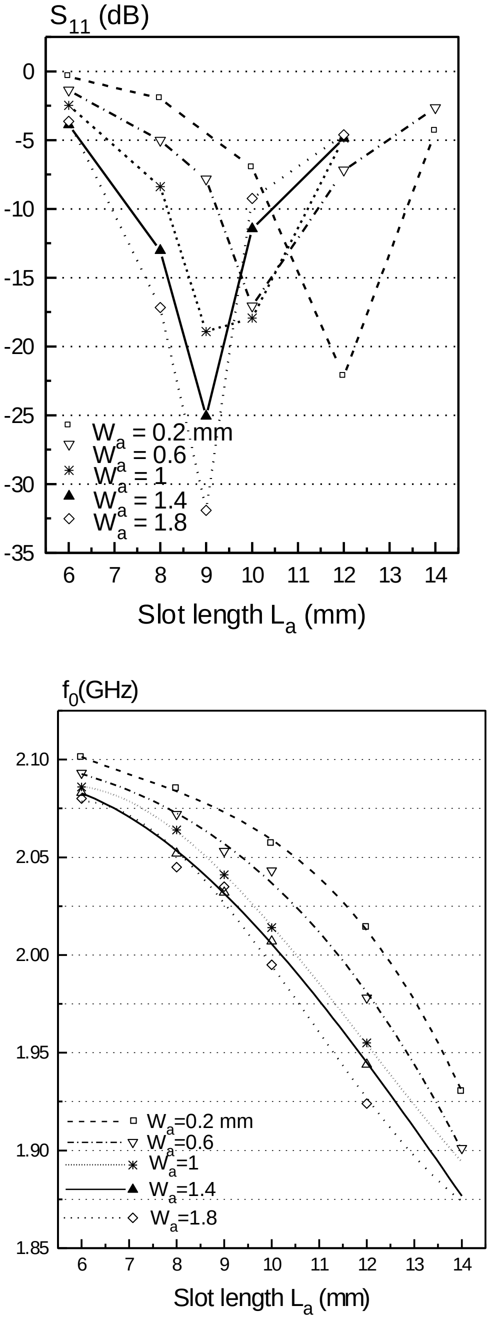

Figure 2: Simulated reflection coefficient of the microstrip-slot coupled RDRA versus slot length and different value of width.

The simulated radiation patterns of the microstrip-slot coupled RDRA shows that the patterns are not much affected by the size of the slot. As shown in Figure 4 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. The experimental results together with the predicted values in the case of optimal matching point at W_a=1.4mm, L_a=9mm are summarized in Table 1.

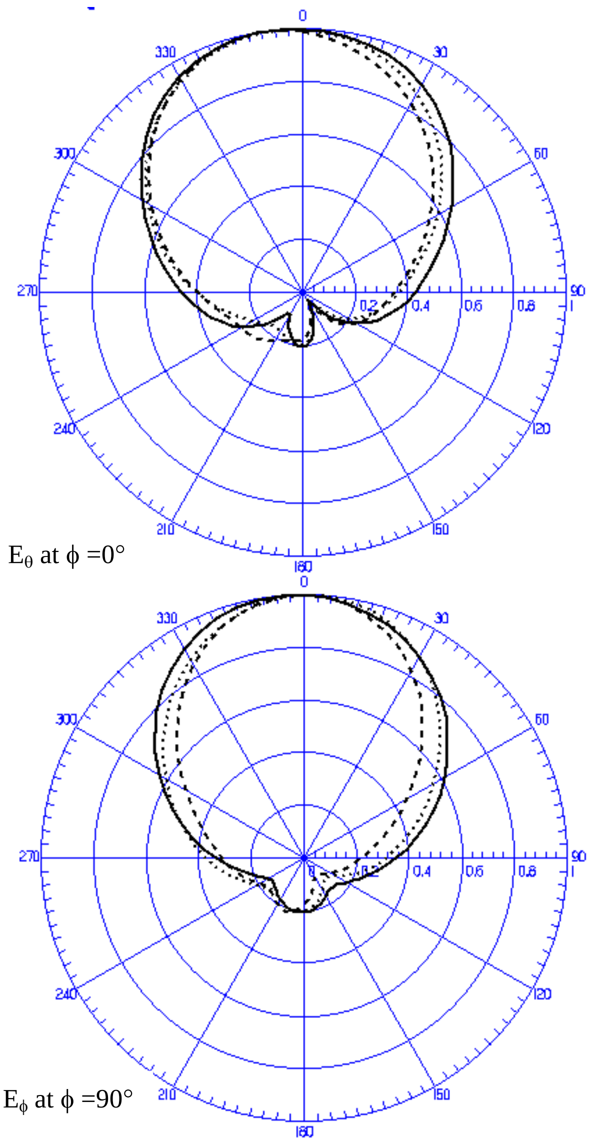

Figure 3: Simulated radiation patterns of the microstrip-slot coupled RDRA for different value of slot length L_a, W_a=1.4 mm and d_x=d_y=g=0.
(L_a= 6 mm - - - - L_a= 9 mm—— L_a=12 mm············)

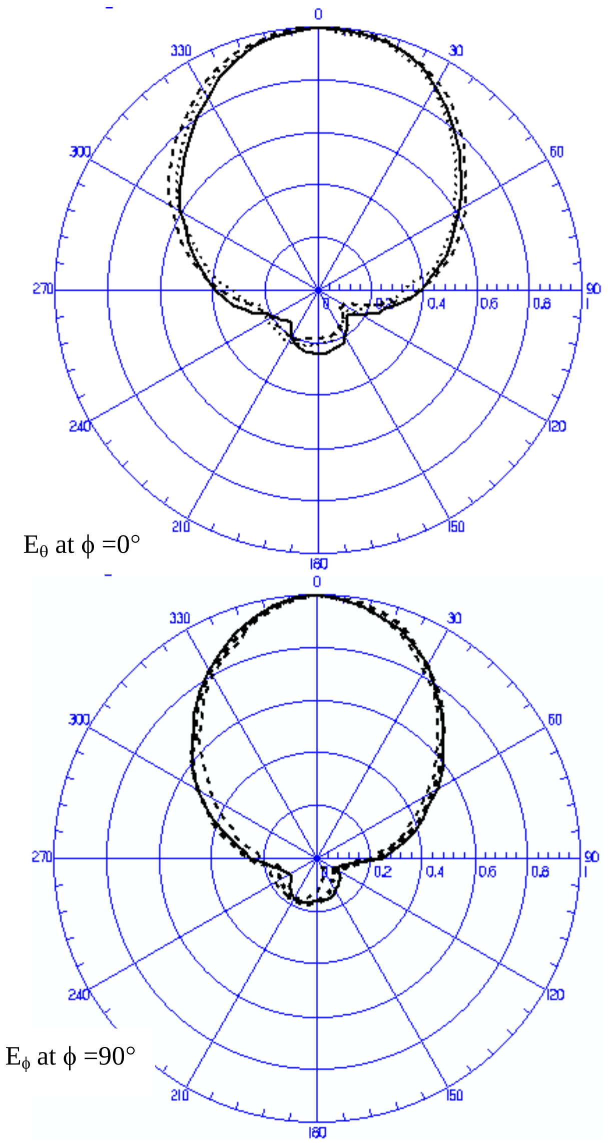

Figure 4: Measured radiation patterns of the microstrip-slot coupled RDRA for W_a=1.4 mm and different slot length L_a , and d_x=d_y=g=0.
(L_a= 6 mm - - - - L_a= 9 mm —— L_a=12 mm ············)

5. Discussion and Conclusions

The microstrip-slot coupled RDRA has been analyzed using the FEM based HFSS. The results indicate that the numerical method can predict the radiation patterns of the antenna well and they are not affected by the size of the slot. There is however an error in resonance frequency and bandwidth of the RDRA compared with the measured values. The resonance frequency may differ by ~7%, and BW by a factor of 1.2. This is believed to be due to the fabrication imperfection such as air gap between the slot and resonator in the antenna structures that is not taken into consideration in numerical modeling.

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

	Simulation	**Measurement**
$\mathbf{f_0}$ (GHz)	**2.032**	**2.147**
$\mathbf{S_{11}}$ (dB)	**-25.064**	**-42.87**
BW (%)	**2.25**	**2.7**
D	**3.54**	**3.02 (Gain)**

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., " Rectangular dielectric resonator antennas: theoretical modelling and experiments.", 11th International Conference on Antenna and Propagation (ICAP2001), 17-20 April 2001, UMIST, Manchester, UK, Vol. 480, pp. 886-870.

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.