THE EFFECT OF AIR GAP ON THE RADIATION PERFORMANCE OF MICROSTRIP-SLOT COUPLED RECTANGULAR DIELECTRIC RESONATOR ANTENNA

M. H. Neshati[1], Z. Wu[2]

1- Electrical Dept. Sistan & Baluchistan University. Zahedan, 98164, Iran.
e-mail: neshat@hamoon.usb.ac.ir

2- University of Manchester, Manchester, UK. Manchester M60 1QD.
zhipeng.wu@manchester.ac.uk

Abstract

A Microstrip-Slot Coupled Rectangular Dielectric Resonator Antenna (RDRA) operated at the dominant TE^{y}_{111} mode of operation is investigated numerically and experimentally. The effect of air gap between feeding slot and the resonator on the radiation performance of the RDRA is studied A few experimental set-ups were also examined and the antenna parameters were measured. It is shown that there is a good agreement between simulated results and those obtained by experiments.

Introduction

Dielectric Resonators (DRs) are widely used in shielded microwave circuits such as filters and oscillators. In 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 [1-3]. Dielectric resonators have been studied in literature in hemispherical, cylindrical, cylindrical ring and rectangular geometry. Compared with the other geometry's, RDRs [4] 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. DRs can be fed using different feed arrangements including coaxial probe, microstrip line, microstrip-slot and co-planner waveguide. The microstrip-slot coupled RDRA was reported numerically and experimentally by author in [5] and it is shown that critical coupling is obtained with an optimum length of the slot:

$$W_a=1.4 \text{ mm}, L_a=9 \text{ mm} \qquad 1$$

where resonator is symmetrically excited by the feeding slot.

In this paper a microstrip-slot coupled RDRA is investigated numerically using a software package based on the Finite Element Method (FEM) and the effect of air gap is considered.

Antenna Structure

The structure of the RDRA under investigation is shown in Figure 1. The resonator is placed above a non-resonant slot etched on the metallic ground plane of a microstrip line providing coupling between the resonator and feed line. The DR with dimensions a=19 mm, b=19 mm and h=9.5 mm is used and the relative dielectric constant of the material is $\varepsilon_r=38$ and *g* is the gap between feed line and DR. For symmetrical excitation of the resonator it is needed that $d_x=d_y=0$. The microstrip line is etched on the topside of a piece of RT/ Duroid 5880 with dimensions 90 mm (length)×70 mm (width)×0.787 mm (thickness), dielectric constant 2.2 and copper thickness 35 µm. The feed line is 2.45mm wide giving a characteristic impedance of 50Ω.

Antenna Simulation

The antenna structure is simulated using the HP85180A High Frequency Structure Simulator (HFSS) [6] which is a software package to calculate S-parameters of the high frequency structures. The simulation technique, based on the FEM, 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, called thetrahedra, and all these elements together are refereed to as 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 analyzed 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 [6]. The radiation surface does not have to be spherical, the only restriction regarding to its 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 on the absorber surface and then calculates the radiation fields. The unloaded Q-factor of the RDRA, Q_0 can be calculated from the reflection response S_{11} against frequency using one-port measurement technique presented by Wu [7]. In particular Q_0 can be expressed as $Q_\tau = \tau Q_\tau$, where Q_τ is the Q-factor at a selected reflection level $S_{11}(f_\tau)$ at *f* given by

$$Q_\tau = \frac{f_0}{2\left|f_0 - f_\tau\right|} \qquad 2$$

where f_0 is the resonance frequency. The parameter τ is a constant depending on the selected reflection given by:

$$\tau = \left[\frac{(1+\beta)^2 \left| S_{11}(f_\tau) \right|^2 - (1-\beta)^2}{1 - \left| S_{11}(f_\tau) \right|^2} \right]^{1/2} \qquad 3$$

where β is the coupling coefficient given by:

$$\beta = \frac{1 \mp \left| S_{11}(f_0) \right|}{1 \pm \left| S_{11}(f_0) \right|} \qquad 4$$

The Effect of Air GAp

The introduction a thin air gap, due to the roughness of the surfaces or failure to ensure complete contact between the resonator and conducting parts of the RDRA structure, may significantly affects the radiation performance of a DRA. When an air gap exists between resonator and ground plane, the electric field component normal to the metallic part of the structure is much stronger in the air gap than inside the resonator, especially, when it is composed of a material of high dielectric constant. A simple theory to model the gap is based on the effective permittivity [8] which is:

$$\varepsilon_{eff} = \frac{H}{\frac{h}{\varepsilon_d} + g} \qquad 5$$

where H is the total height of the antenna, h is the height of the resonator and g is the gap between DR and ground plane. It can be seen that considering an air gap in the antenna structure, the dielectric constant is reduced and in turn the resonance frequency is increased.

Results

Fig 2 and 3 shows the numerical results of coupling coefficient, resonance frequency and reflection coefficient against air gap. It can be seen that with increase in the air gap, the coupling coefficient decrease and both the resonance frequency and return loss increase.

The simulated radiation patterns for various values of air gap, g is presented in Fig 4. It can be observed that the radiation patterns becomes more directive with respect to the radiation patterns for g = 0. However, the radiation patterns change slightly overall.

The simulated and measured results of the microstrip-slot coupled RDRA at the best copling condition, in equation 1, are shown in table 1. The measured values of resonance frequency are higher than that obtained from simulation. The error may reach ~7% in case of zero air gap (g=0). However, considering the air gap in th antenna structure based on equation 5 and the antenna parameters shows that error in case of g = 0.03 cm decreases to 2%. Moreover, table 1 show that considering air gap between resonator and feed slot in numerical procedure, the accuracy of the resonance frequency, Q-factor and impedance bandwidth is highly improved.

Conclusion

In this paper a microstrip-coupled RDRA was studied numerically and experimentally and the effect of air gap on the radiation performance was presented. The HFSS software package was used to analyze the antenna. A few set-ups were implemented for measurements. Results show a good agreement between simulation and experimental results. However, better agreement could be obtained by considering the fabrication imperfection such as air gap between resonator and feed line that is needed to be taken into consideration in numerical modeling to produce more accurate prediction of the RDRA characteristics.

References

[1] McAllister, M. W., Long, S.A. and Conway, G.L., "Rectangular Dielectric Resonator Antenna", Electronics Letter. , 1998, 19, pp. 218-219

[2] Mongia, R. K., "Theoretical and Experimental Resonance Frequencies of Rectangular Dielectric Resonators ", IEE Proceedings-H, 1992, 139, pp. 98-104.

[3] Mongia, R. K. and Bharita, "Dielectric Resonator Antenna- A Review & general Design Relations to Resonant Frequency and Bandwidth", International Journal of Microwave & Millimeter-Wave Computer Aided Engineering, Vol. 4, 1994, pp. 230-247.

[4] Neshati M. H. and Wu, Z., "Probe-fed Rectangular Dielectric Resonator Antennas: Theoretical Modeling & Experiments", International Journal of Engineering (IJE), Vol. 16, No. 1, Feb. 2003, pp. 41-46., Tehran, Iran.

[5] Neshati M. H. and Wu, Z., "Finite Element Analysis of and Experimental studies of Microstrip-slot Coupled RDRA" International Conference on Microwave and Millimeter wave Technology, ICMMT 2004, Aug, 18-21, 2004 Proceeding pp. 448-451, Beijing Convention Centre, China.

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

[7] Wu Z., and Davis L. E., "Automation-Oriented Techniques for Quality-Factor Measurement of high T_c Super conducting Resonators", IEE Proceedings of Science, Measurement & Technology", 1994, Vol.141, pp. 427-430.

[8] A. Buerkle, K. Sarabandi, H. Moallaei, "Compact Slot and Dielectric Resonator Antenna With Dual-Resonance, Broadband Characteristics", IEEE Transaction on Antenna & Propagation. Vol., AP 53, No. 3, March 2005, pp. 1020-1027.

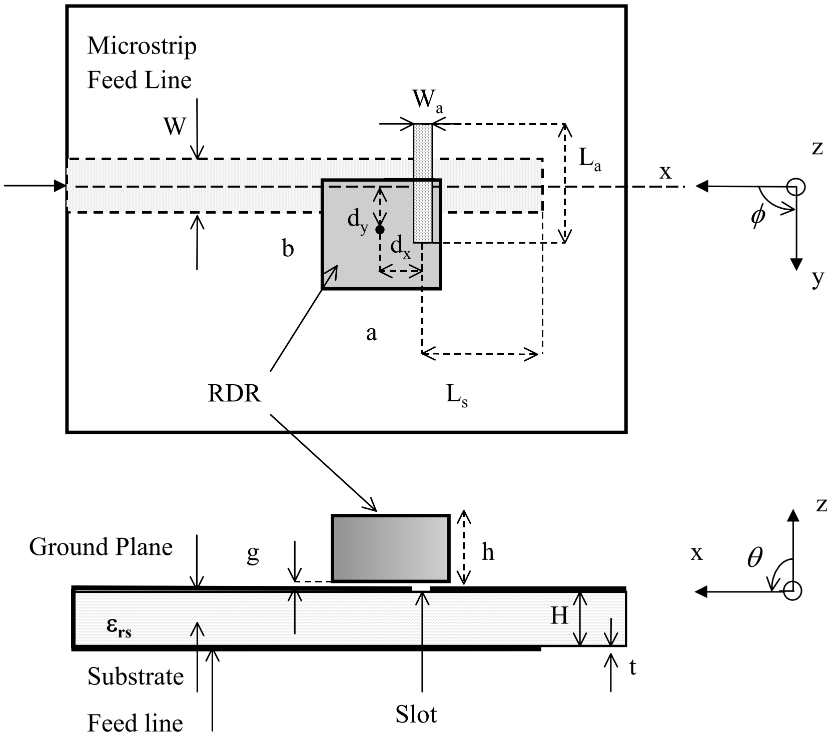


Figure 1: The geometry of the microstrip-slot coupled RDRA

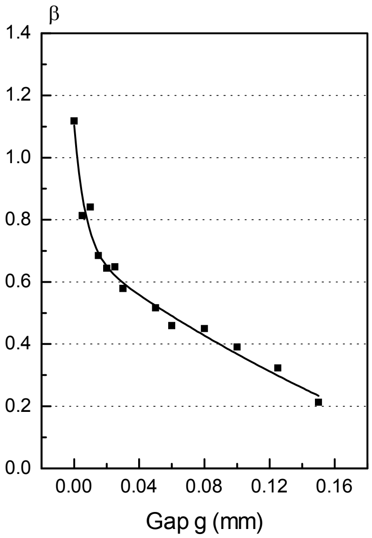


Figure 2: Simulated coupling coefficient versus air gap *g* of the microstrip-slot coupled RDRA.

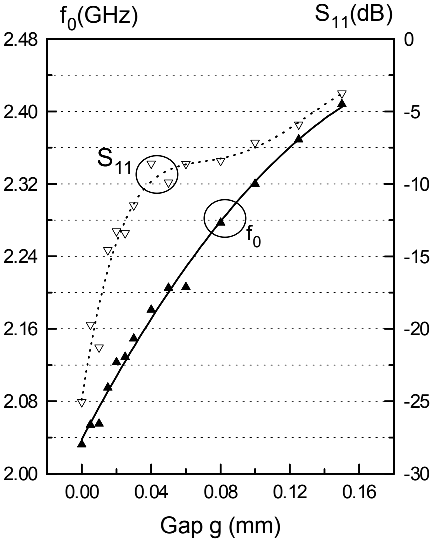
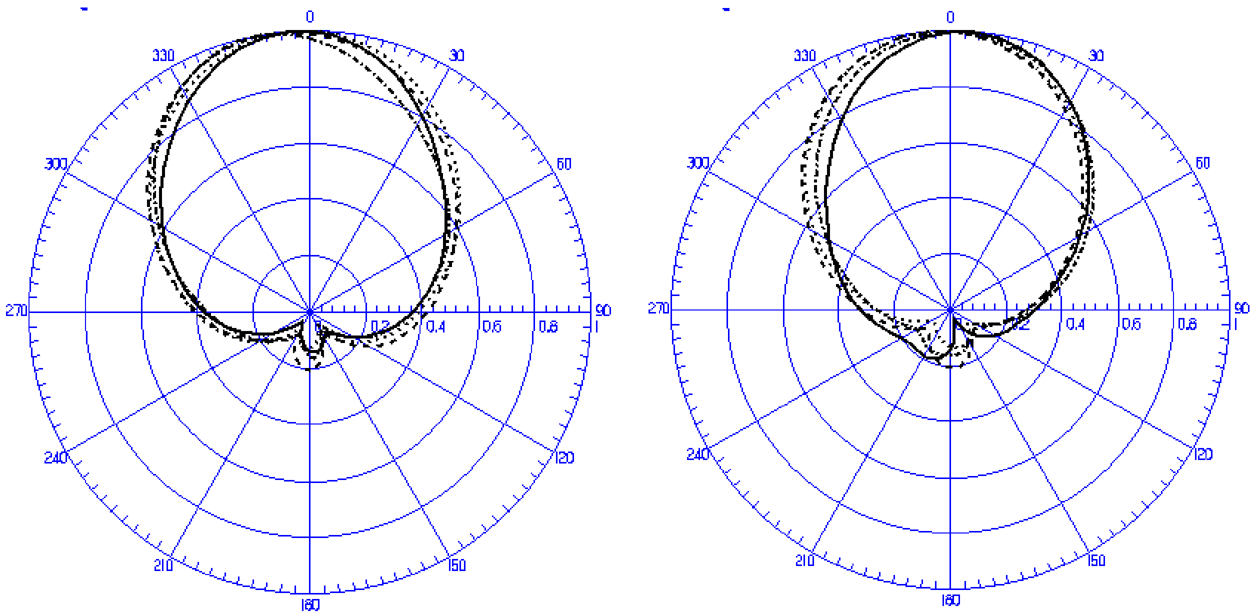


Figure 3: Simulated return loss & resonance frequency versus air gap *g* of the microstrip-slot coupled RDRA.



E_θ at ϕ=0°

E_ϕ at ϕ=90°

Figure 4: Simulated co-polarization radiation patterns of the RDRA for various values of air gap *g*.

g =0.005 mm ———— *g* = 0.025 mm - - - - - -

g =0.06 mm ·········· *g* =0.1 mm - · - · - · -

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

Parameter	**Simulation**		**Measurement**
	g = 0	**g = 0.03 mm**	
$\mathbf{f_0}$ (GHz)	2.032	2.145	2.147
Return loss (dB)	25.064	36.56	42.877
Coupling Coefficient β	1.118	1.01	1.014
Q-factor	44.45	36.8	37.0
BW (%) VSWR≤2.6	2.25	2.7	2.7