Modeling of Conical Dielectric Resonator by Simulation at 10 GHz and Comparing with the Cylindrical Dielectric Resonator

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Abstract

In this paper, the finite element method is applied to simulate a conical dielectric resonator coupled to a microstrip line at 10 GHz using HFSS. It is modeled with a RLC network and the value of equivalent circuit elements are extracted. Then the response of this circuit with the simulation results has been compared. The work has been carried out on the dielectric resonator in different distances in order to find such relation in equivalent circuit. Also a comparison is carried out by simulating the cylindrical one at the same frequency.

Keywords: conical, cylindrical, dielectric resonator(DR), equivalent circuit, microstrip, HFSS

I. Introduction

Due to reducing the cost of microwave circuits, it is necessary to decrease the dimensions as possible. The technology efforts in this case, have resulted in many achievements. Dielectric resonators(DR) are one of the most important achievements that are widely used in microwave circuits and applications, like filters, oscillators, frequency meters, tuned amplifiers and many other circuits. Dielectric resonators are made of high dielectric constant and low loss materials and can be found in different shapes. A very common dielectric resonator shape is the cylinder. Different analysis for this case have been reported [1], [2], [3], [4]. They prepare formulas for designing dielectric resonators. Also a RLC network has been introduced as an equivalent circuit and formulas for relating this resonator to such a resonant circuit, have been presented [1], [5]. But recently, conical dielectric resonator has been introduced in some applications. Specially, the most work has been done on conical dielectric resonator antennas [6], [7]. Also it has been analyzed in a special configuration in MIC environment, mostly suitable for coupling to a ring resonator [8], [9]. In this paper, first a cylindrical dielectric resonator is analyzed by HFSS at 10 GHz and the results are compared. Then the value of the equivalent circuit elements are extracted and the response of such circuit is compared with the HFSS results. The steps are repeated on conical dielectric resonator at the same frequency in comparison.

II. Theory

Although dielectric resonator has a very simple shape, solving Maxwell equations is too hard to be done analytically. As mentioned before, the problem has been analyzed with different numerical methods, each of them made some approximations and have different accuracies. In general, the resonator dimensions and shielding conditions determine the resonant frequency [10]. In this paper, a cylindrical dielectric resonator is analyzed in MIC configuration by HFSS which uses finite element method and the results are compared. Also computer programs have been developed in MATLAB to analyze the HFSS results and extract the value of R, L, and C in the equivalent circuit. Then by simulating such circuit, the validity of this equivalency has been checked.

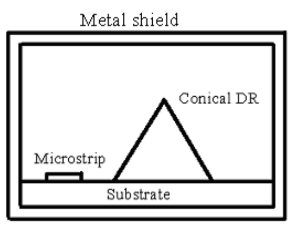

Fig.1 A conical DR coupled to microstrip line.

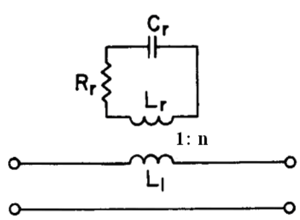

Fig.2 simplified RLC equivalent circuit for a DR coupled to microstrip line.

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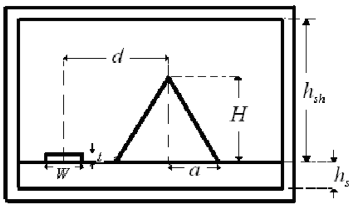
These formulas has been presented by [5] in a parallel resonant circuit approach as

$$R_r = \frac{2\, n^2\, z_0\, s_{110}}{1 - s_{110}}$$
$$C_r = \frac{Q_0}{\omega_0\, R_r} \qquad (1)$$
$$L_r = \frac{1}{C_r \omega_0^2}$$

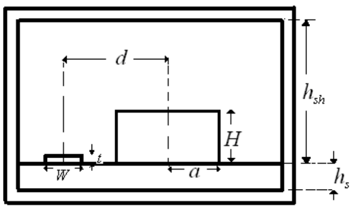
The turns ratio(n) is a parameter for describing the coupling between resonator and microstrip line. It is related to distance between resonator and microstrip line. It is mentioned in [5] that the value of R can be chosen. Since we have four unknowns in the three equations in (1). But during programming, it is preferred to chose a suitable value for n and to find the value of R. Since R appears in two equations finding a suitable value for it, is more complicated.
The steps are repeated on a conical dielectric resonator at the same frequency. A comparison is done on the two cases.

III. Simulation

The formulas in [10] have been used to determine the cylindrical dielectric resonator dimensions for desired frequency. By some qualitative considerations about the resonant frequency, the physical dimensions of the conical dielectric resonator as in figures 3a,b has been determined and checked by HFSS.



(a)



(b)

Fig. 3 simulated configuration. a)conical DR b)cylindrical DR
In both cases (a) and (b) :

$W = 2.4(mm), t = 17(\mu m), h_s = 0.787(mm), \varepsilon_s = 2.2, h_{sh} = 4.2(mm)$

d is changing between 5.9(mm) and 7.3(mm)

(a)

$a = 4.6(mm), H = 2.9(mm), \varepsilon_r = 37$

(b)

$a = 4.6(mm), H = 1.3(mm), \varepsilon_r = 37$

Which ε_s is the substrate relative permittivity and ε_r is the DR relative permittivity. In both cases, DR radius and shield height are chosen the same because of comparison in MIC application.

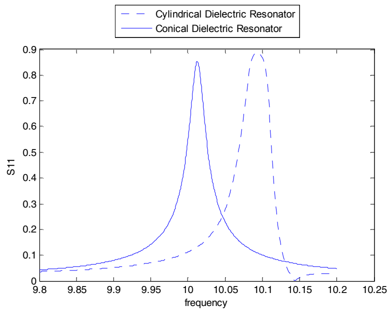
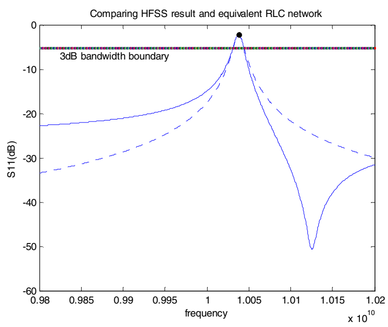


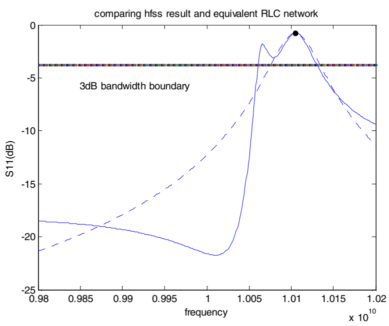
Fig. 4 s_{11} for both DRs about the resonant frequency. Accuracy is better than 2% as expected.

Simulation has been done for fifteen different distances and the results for two dielectric resonators and their equivalent network responses are compared. Computer programs have been developed in MATLAB to analyze the HFSS results and extract the value of R, L, and C in the equivalent circuit.

The results are shown for three d(near, far, and middle distance related to microstrip line) in the figures 5 to 7.

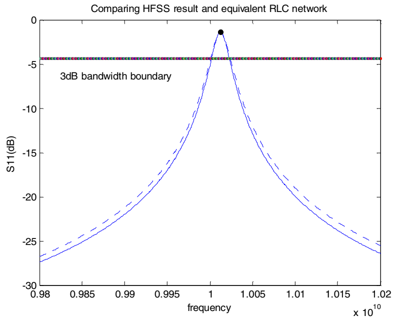


(a)

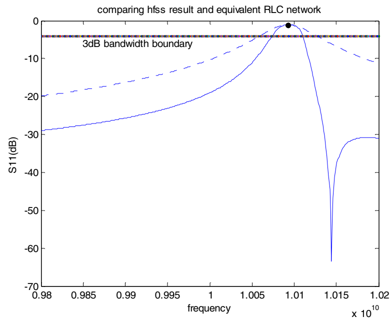


(b)

Fig. 5 s_{11} versus frequency for conical and cylindrical DRs and their equivalent networks. The dashed line corresponds to the equivalent RLC network. (a)conical DR, (b)cylindrical DR. d = 5.9(mm)

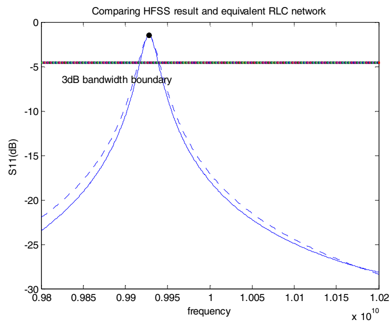


(a)

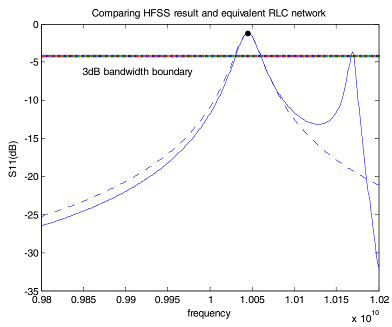


(b)

Fig. 6 s_{11} versus frequency for conical and cylindrical DRs and their equivalent networks. The dashed line corresponds to the equivalent RLC network. (a)conical DR, (b)cylindrical DR. d = 6.4(mm)



(a)



(b)

Fig. 7 s_{11} versus frequency for conical and cylindrical DRs and their equivalent networks. The dashed line corresponds to the equivalent RLC network. (a)conical DR, (b)cylindrical DR. d = 7.2(mm)

Due to changing the distance, a shift is seen in the resonant frequency. But the formulas have not been considered it. Of course, the shift is less than what accuracy supports and hence can be neglected. But in the case of comparison, the resonant frequency in the conical DR shifted more than the cylindrical one, about 0.025 GHz. But the most important comparison is how the RLC equivalent circuit is matched to the real problem. As it has been seen, the conical DR has a very good matching in all distances rather than cylindrical one which it was not matched even in the 3dB bandwidth. Specially when it is settled in the middle distances. It is because of the anti resonance modes which are stronger in the cylindrical DR. It is interesting to notice figures 5.b and 7.b. It seems that the RLC circuit response is approaching to HFSS result as such anti resonance modes are coming out. It happens when cylindrical DR is so close to the microstrip and to the shield wall. Although conical DR can be used in broadband antenna applications in different configurations, it can be seen that it has higher Q factor than cylinder in MIC configuration.

The other part is to determine the relation between physical distance of the DR and microstrip line and turns ratio in the equivalent circuit for these two cases. As mentioned, the shift in the resonant frequency can be neglected. Also a variation is seen in the value of unloaded Q factor[1](Q_0) that results in modifying turns ratio in the equivalent circuit. In order to find such a relation, the value of C in the equivalent circuit is assumed constant to have a fixed resonant frequency. Hence the value of R is changed so that it compensates the change in the value of Q_0. Hence the ratio of Q factors determines the ratio of Rs. So the value of n can be found by setting the value of n related to d=5.9(mm), as a reference, the variation of n can be calculated by

$$n_2 = n_1 \sqrt{\frac{Q_{0_2}}{Q_{0_1}}} \qquad (2)$$

As mentioned, both cylindrical and conical DRs are analyzed in fifteen different distances. First, n is chosen so that RLC network response matches to the HFSS result, specially in resonant frequency. Then the resonant frequency is assumed completely fixed and the relation between n and d is calculated by considering the Q variation.

Table 1 shows unloaded Q factors and the value of n in the equivalent circuit for different distances achieved by such calculations. Also the values of unloaded Q factors for different distances are plotted in figure 8.

[1] The unloaded Q factor is the Q factor that is defined by the losses of cavity or resonator itself as the ratio of maximum energy storage during a cycle to average energy dissipated per cycle.

Table 1 the value of turns ratio in different distances for both DRs

Distance (mm)	conical DR		cylindrical DR	
	Unloaded Q factor	Turns ratio(n)	Unloaded Q factor	Turns ratio(n)
5.9	3.3460e+003	1.0100	2.0210e+003	1.0100
6	2.8671e+003	0.9349	1.1211e+003	0.7522
6.1	3.3457e+003	1.0100	1.2630e+003	0.7984
6.2	2.8654e+003	0.9347	1.2630e+003	0.7983
6.3	2.8653e+003	0.9346	1.2624e+003	0.7982
6.4	2.8607e+003	0.9339	1.2616e+003	0.7980
6.5	2.8631e+003	0.9343	1.4410e+003	0.8528
6.6	2.8616e+003	0.9340	2.0168e+003	1.0089
6.7	2.8593e+003	0.9337	2.0160e+003	1.0087
6.8	2.5003e+003	0.8731	2.5200e+003	1.1278
6.9	2.4989e+003	0.8728	2.0150e+003	1.0085
7	2.4960e+003	0.8723	2.5175e+003	1.1273
7.1	2.4894e+003	0.8712	2.0118e+003	1.0077
7.2	2.4820e+003	0.8699	2.0113e+003	1.0076
7.3	2.4778e+003	0.8691	2.0006e+003	1.0049

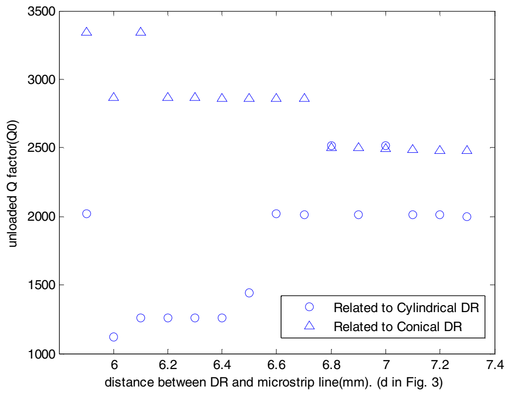


Fig. 8 unloaded Q factor(Q_0) versus physical distance(d)

It can bee seen that Q_0 in conical DR is higher than cylindrical one and has monotonically decreasing variations rather than cylindrical DR.

IV.Conclusions

In this paper, a conical DR is designed by simple tuning over the relations for conventional cylindrical DR and simulated by HFSS at 10 GHz. Also the values of equivalent circuit elements are extracted and the ability of such circuit for describing the physical problem is checked. Although the variation of turns ratio relative to the distance between conical DR and microstrip line is calculated. The steps are repeated for cylindrical case for comparison.

it is understood that anti resonance modes in conical DR, are farther from resonant mode than those in cylindrical DR. Since it can be approximated by one RLC network better than cylindrical DR. Also it can be seen that the loaded Q factor of conic is higher(nearly twice) the cylinder. So it is desirable using conical DR in selective filters which need more resolution in resonant frequency and higher Q factor. Also more bandwidths can be achieved by using an array of conical DRs. It is valuable to notice that such configuration of settling conical DR is easy and stable rather than spherical DRs and also provides higher Q factor than cylindrical DRs. In this case it can be seen that the volume of conical DR is less(nearly 0.74) than the cylindrical one and hence the weight and the amount of material used, are less. It maybe seem undesirable the higher height of conical DR. But since the height of the shielding box is not changed, the higher height can be neglected in MIC applications.

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