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Resonant Behavior Analysis of Split-Ring Resonator Due to Positional Change of Dielectric Material

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ABSTRACT

In this paper tunability characteristics of split ring resonator has been explored for dielectric materials. Effects on resonant behavior of resonator due to change in horizontal position of materials has been analyzed with the help of simulations. In this work, perturbation of electric field in resonator gap has been studied with regards to changing position for different dielectric materials. Variation in horizontal position of materials resulted in change in resonant behavior of the resonator. These were observed with the help of simulation results. Shifts in values has been found relative to permittivity of dielectric materials. Shifts in resonant behavior due to change in material position can be utilized in numerous applications**.**

KEYWORDS

Split ring resonator, dielectric material, perturbation, tunability, positional change, permittivity.

1 INTRODUCTION

Split ring resonator (SRR), also known as loop gap resonator or open loop resonator is used as an important component in numerous high frequency circuits including filters, oscillators, and tuned amplifiers [1]. This type of resonator is characterized with moderate quality factor, low phase noise, low cost and ease of fabrication [2]. SRR also find application in metamaterial at very high frequencies [3]. Composition analysis of liquid solvents has been performed using this resonant structure. Its usability has been demonstrated for characterizing fluid in flowing condition [4]. It has also been designed for use as a noninvasive biomedical sensor for monitoring blood glucose [5].Sensitivity analysis of polar liquids has also been performed using this resonant structure [6].

A SRR, enclosed in a shield as shown in Fig.1, can be modeled as a LC circuit. The metallic loop acts as an inductor and the longitudinal gap acts as a capacitor. The magnetic field surrounds the loop as it acts a inductor and the electric field is produced in the gap as it acts as a capacitance [7],[8].Where resonant frequency is given below.

$$\mathrm{f}_0 = 1/2\pi\sqrt{\mathrm{LC}} \tag{1}$$

Where inductance *L* and capacitance *C* can be found by the classical formula mentioned below.

$$\mathrm{L} = \mu_0 \pi \mathrm{r}_0{}^2/\mathrm{Z} \tag{2}$$

$$\mathrm{C} = \varepsilon \mathrm{WZ}/\mathrm{t} \tag{3}$$

Where r_o is the radius of the resonator, *t* is the width of the gap, *W* is the width of the resonator and *Z* is the height of the resonator [9].

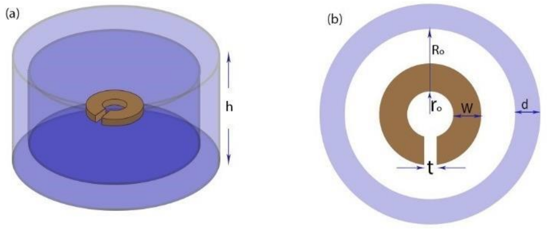


Figure 1. (a)Split ring resonator enclosed in shield (b) Cross section

The resonator quality factor is defined as [7]:

$$Q = \omega_0 (U_{tot}/P) \tag{4}$$

Where U_{tot} is time averaged stored energy, P is time averaged power dissipation. And ω_o is angular resonant frequency.

Different models were obtained for calculating resonant frequency of the SRR [2] . For this study the expression for resonant frequency are given below [8],[9],[10].

$$f_0 = \frac{c}{2\pi r_0}\sqrt{\frac{t}{\pi W}}\sqrt{1+\frac{r_0^2}{R_0^2+(r_0+W)^2}}\sqrt{\frac{1+{}^{\Delta Z}/_{Z}}{1+{}^{\Delta W}/_{W}}} \tag{5}$$

Where

$$\Delta Z \approx 0.18 R_0 \tag{6}$$

$$\Delta W \approx 3t \tag{7}$$

The main method for microwave characterization of materials fall into two categories

- Resonant
- Non-resonant

Non-resonant methods are used to obtain electromagnetic properties over a broad frequency range and resonant methods are used to get dielectric properties at a single frequencies or several discrete frequencies. These methods are often used in combination [11].

Resonant methods are based upon perturbation theory. Using this theory, permittivity of a material is determined by observing change in values of resonant frequency and quality factor of the resonator when a material is placed in resonator's gap. This method is also referred as material perturbation method. Which in short says that for a resonator with stated electromagnetic boundaries a part of the electromagnetic boundary condition is changed by an introduction of a material its resonant frequency and quality factor also change. Fig. 2 shows the system before and after the introduction of the material. From the change in resonant properties the calculation of important parameters of the sample are possible [12].

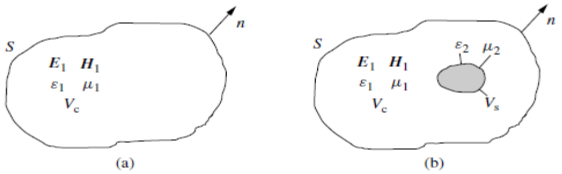


Figure 2. (a) Undisturbed system (b) Disturbed system after insertion of material

The relationship between real and imaginary part of permittivity, resonant frequency and quality factor is given follow [13]:

$$\varepsilon_r' \propto \Delta f_0 \tag{8}$$

$$\varepsilon_r'' \propto \Delta(1/Q) \tag{9}$$

Where ε_r' is real part of the relative permittivity and ε_r'' is its complex part. And Δf_o is difference in resonant frequency from resonant structure and similarly $\Delta(1/Q)$ is quality factor difference from resonant structure.

This paper explores tunability characteristics of SRR and presents analysis of shift in resonant properties of the resonator with change in position of dielectric material placed in resonator's gap. A suitable SRR design has been achieved using HFSS simulation. Change in resonant properties is observed with respect to the horizontal position of sample materials. Shift in resonant behaviors is analyzed and possible applications are explored in the following sections.

2 DESIGN

The aim was to design a SRR structure using HFSS, which yields a resonant frequency of about 3 GHz. Split ring was designed using copper due to high conductivity of material. The shield that surrounds the resonator is made up of aluminum. The purpose is to minimize the conduction and electromagnetic wave losses. The aforementioned losses are desired to be kept as low as possible for a better quality factor and resonant frequency. Also, the shield helps protect the resonator and whole project mechanism within from the external radiations. Thus improving the isolation of the device to enhance and eventually insuring the quality factor and resonant frequency.

Design parameters were varied and resonant behavior studied to finalize the design. The effect of shield was also observed during simulations by varying the parameters of the shield. The process of varying resonator's parameters was repeated till the desired value was obtained and design parameters of the resonator were finalized. Several design equation were also utilized in order to attain a feasible and appropriate design. It was found that (5), mentioned above, provides result closer to simulated values as this equation takes into account the effect of the shield [8]. Parameters of the final design are illustrated in table 1.

Table 1. Final design of SRR

Parameters	Values
Resonator Dimensions (mm)	
Inner radius of SRR (r_o)	5
Width (W)	4
Length (Z)	9
Gap (t)	2.9
Outer radius of SRR ($r_o + W$)	9
Shield Dimensions (mm)	
Outer radius	33
Inner radius (R_o)	23
Thickness (d)	10
Height (h)	50
Resonant Parameters	
Resonant Frequency ***(GHz)***	3.04
Quality Factor	3486

3 SIMULATION RESULTS

For the purpose of simulation the dielectric sample material was slid through the resonator gap. Effects of sliding was observed with the help of software. The position was initially positioned as just entering into the resonator gap. Then it was moved into slightly the gap while most of the gap remained empty. Half of the gap was then occupied by the sample material. The sample material then occupied most of the gap and subsequently it completely occupied the gap. It was moved out of the gap from the other end in a similar fashion. Effects of its movement on resonant behavior of SRR was observed for each step. Two dielectric materials were used and their dielectric properties are given in following table [14],[15].

Table 2. Dielectric constant of sample materials

Sample material	Real Permittivity	Complex Permittivity
Rubber	2.35	0.0021
Nylon	3.154	0.0662

When a sample material is introduced into the system, electromagnetic energies in the gap changes. As a result resonant frequency shifts from its previous value. Also, the quality factor of the system shifts because of the same reason. When it is further moved within the gap of the resonator, the resonant parameters experience shift accordingly. Thus, as it is moved from one end of the split of the resonator to the other end, the shift in resonant frequency and quality factor is observed and data gathered. The simulation results are as shown in Fig. 3 to 6.

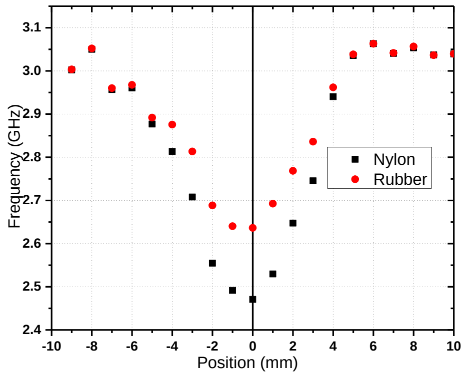


Figure 3. Resonant frequency vs position of sample material.

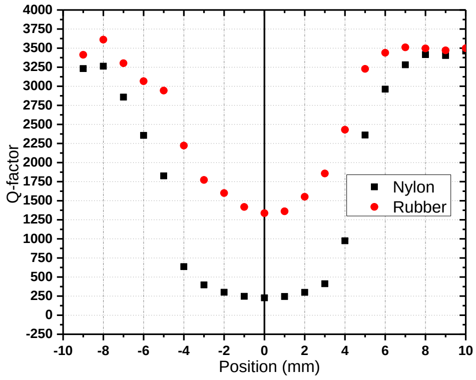


Figure 4. Quality factor vs position of sample material

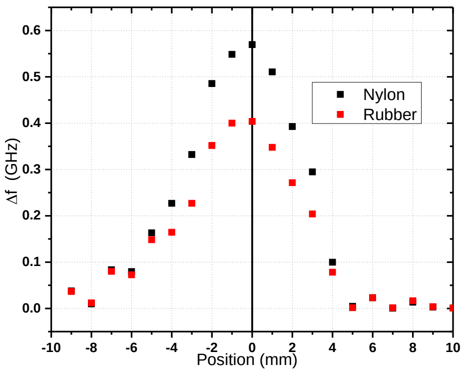


Figure 5. Resonant frequency shift vs position of sample material.

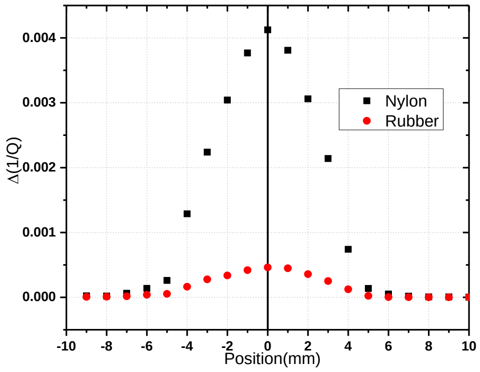
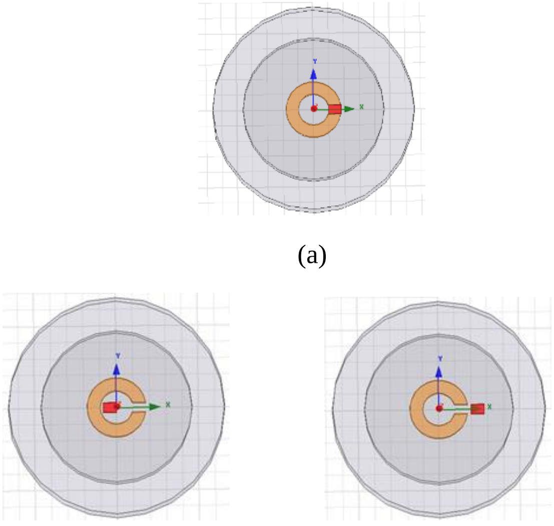


Figure 6. Quality factor difference vs position of sample material.



(a)

(b)

(c)

Figure 7. (a) Central position (b) Position at -10mm (c) Position at 10mm

In these graphs, the central position marks center of the gap of the resonator and the positions left and right from the center show the horizontal movement in mm from the center. From the Fig. 3 to 6, it can be observed that the resonant frequency and quality factor responses vary after the introduction of the sample. Also response varies as sample is moved from the center of the gap to the outer edges of the gap of the resonator.

4 DISCUSSION

SRR acts as a LC circuit in which an electric and magnetic field is induced when it is energized. Electric field is strongest in center of the resonator gap. Whereas magnetic field is strongest at the other end [7],[8]. As observed in the previous section the change in value of resonant frequency and quality factor are due to the introduction of the sample material in to the resonator gap in Fig. 3 and 4. Similarly, effects can be observed for shifts in resonant frequency and quality factor in Fig. 5 and 6 respectively.

As seen in Fig. 3, maximum change in resonant frequency is observed when sample material completely occupies the resonator gap. Highest shift in resonant frequency is observed for this position of material as shown in Fig. 5. It is inferred from this observation that the strongest response is obtained when the electric field is completely perturbed by the material. Similar conclusions can be reached for quality factor as observed in the Fig. 4 and 6.

There also is a change in the magnitude of the shift for the two materials. This is because of the fact that both materials have different relative permittivity. As seen in the above table Nylon has higher real and complex permittivity. Shifts in these parameters are dependent upon real and imaginary parts of permittivity as can be established from (8) and (9) respectively. This observation for the two parts of permittivity has been shown in Fig. 5 and 6 respectively.

Fig. 5 and 6 show that difference in shift depends upon the value of relative permittivity of sample material. When a sample material is introduced in the resonator gap, the energy stored changes. The larger the relative permittivity of the sample the greater the difference with the resonant frequency. Fig. 5 shows that difference in resonant frequency shift is larger where the relative real part of permittivity ε_r' is higher. A similar observation is also made in Fig. 6. When a sample is introduced in the resonator gap the quality factor value changes and the extent of this change is effected by imaginary part of relative permittivity. It can be observed that the Sample with higher imaginary part of relative permittivity has a larger difference in quality factor. From which it can be inferred that the material with greater ε_r'' has greater losses and vice versa.

From the above discussion and analysis, it is evident that resonant response of SRR corresponds not only to the values of relative permittivity of sample but also its position in resonator gap. Shift in resonant frequency corresponds to real part of relative permittivity as given in (8) while shift in imaginary part of relative permittivity corresponds to the quality factor as given in (9). Additionally, real part of relative permittivity has little effect on the quality factor whereas imaginary part of relative permittivity has little effect on the resonant frequency response. This can be shown by simulating the above samples by keeping the complex part equal to zero. It can be observed that the responses on the quality factor of both samples are broadly similar. The results of Fig. 8 are comparable with Fig. 5. While results from Fig. 9 shows that, the quality factor difference of both samples becomes more comparable with each other in comparison to Fig. 6.

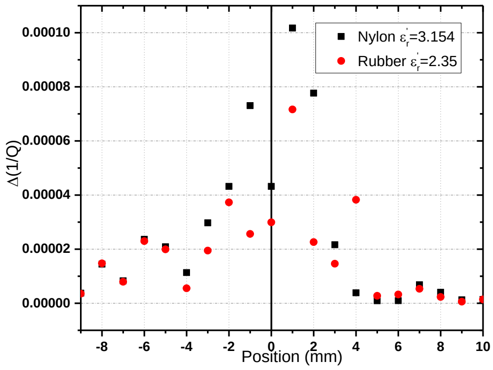


Figure 8. Resonant frequency difference vs position of sample material at $\varepsilon_r'' = 0$.

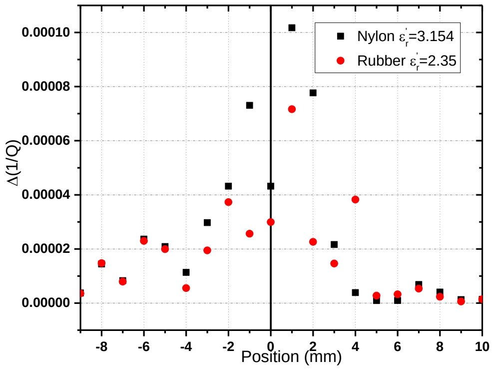


Figure 9. Quality factor difference vs position of sample material at $\varepsilon_r'' = 0$

The results from above discussion suggest that position of sample material in resonator gap has an effect on shift in resonant properties. Magnitude of shift is dependent on the value of relative permittivity ε_r where the real part corresponds resonant frequency shift and imaginary part corresponds to shift in quality factor.

5 CONCLUSION

In this paper, a simulation based analysis has been presented for positional analysis of dielectrics in the gap of the SRR. To obtain values of shift in the resonant frequency and Quality factor, analysis was carried out by changing position of the dielectric in the resonator. The position was varied from the inner edge to the outer edge of the resonator. Simulation results demonstrate that shifts in resonant parameters is more significant when the sample material is placed at the center of the SRR gap where the capacitance is maximum. Comparison amongst the effects of the sample materials depicts that permittivity influences the resonant response. As, nylon has higher relative permittivity, hence, the shift in resonant frequency and Quality factor is the highest for nylon. Whereas, rubber has lower relative permittivity value amongst the two and it demonstrates the least shift in resonant frequency and Quality factor. Research made in this paper provides guidelines for analyzing effects of movement of dielectric inside the gap of SRR and shows by changing the position of the dielectric, the resonant response can be tuned to a certain extent. And it can also be applied for permittivity sensing.

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