

# Design And Analysis Of Dual Split Ring Resonator

[Hina Imtiaz] [Tahir Ejaz] [Tahir Zaidi] [Zainab Nisha Khan]

**Abstract**—In this study a novel non-planar dual split ring resonator (DSRR) has been proposed to achieve high sensitivity and produce variable resonant frequencies and quality factors. This has been achieved by varying distance between two conventional split ring resonators (SRRs). Four different materials i.e. glass, mica, rubber and plastic are used for the analysis of SRR and DSRR. Effects on quality factor and resonant frequency of the two structures through HFSS software has been studied. Due to the insertion of materials in gap of resonator, electric field is perturbed. Perturbation results change in resonant frequency and quality factor of resonator. It was observed that different material resulted shifts in resonant frequency and quality factor in different manner due to unique material permittivity. Hence different sets of shifts in resonant properties were obtained. Results of both conventional and proposed design are presented and compared.

**Keywords**—dual split ring resonator, sensitivity analysis, resonant behavior, perturbation.

## I. Introduction

Microwave techniques are widely used in many applications such as processing of food, plastic, rubber, food grading, ceramic etc. for quality control and characterization [1]. Resonance based systems are preferred due to its accuracy. Perfection and precision can be obtained by taking into account the sensitivity of resonator structures. Different resonator structures i.e. loop gap resonator [2], cavity resonator, hairpin resonator [3] etc. have been used for the characterization of materials. Resonant circuits are formed either by distributed elements or by lumped elements. In lumped elements circuits, capacitor and inductor store electric and magnetic energy [4]. Resonator vibrate at a peculiar frequency called resonant frequency ( $f_r$ ) and quantity to characterize the effectiveness of resonator is known as quality factor ( $Q$ ) [5, 6]. SRR constitute of a metallic cylinder having a gap. It is considered as lumped element circuit in which metallic cylinder act as inductor and gap act as capacitor where electric field is maximum inside the gap and magnetic field is maximum at the other end of metallic cylinder.

Due to low noise, low cost, and moderate  $Q$  of split ring resonator, numerous researches have been performed to enhance sensitivity of structure using different techniques. It has been observed that split ring resonator can be effectively used for highly sensitive material analysis [5]. Geometry used for the analysis of SRR is shown in Fig.1 [7]. This structure exhibit resonance and can be used in many applications [8]. The SRR can be modeled effectively as series LC circuit shown in the figure and calculated using equations (1) and (2).

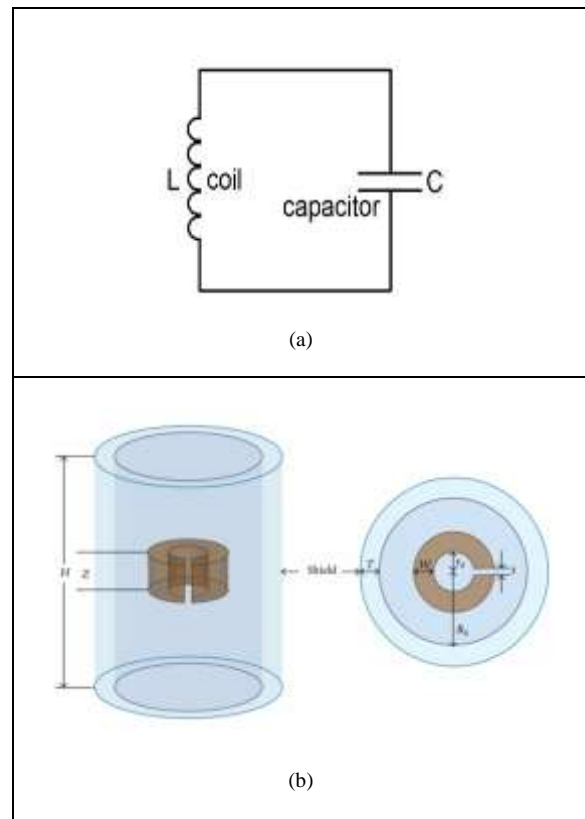


Figure 1. (a) Equivalent LC circuit of SRR (b) SRR model

$$L = \frac{\mu_0 \pi r_0^2}{Z} \quad (1)$$

$$C = \frac{\epsilon_0 Z W}{t} \quad (2)$$

where  $Z$  is the height of resonator,  $r_0$  is the radius of resonator,  $\mu_0$  is the permeability of free space,  $\epsilon_0$  is the

Hina Imtiaz (Author)  
 National University of  
 Sciences and Technology,  
 Pakistan

Tahir Ejaz (Author)  
 HITEC University,  
 Pakistan

Tahir Zaidi (Author)  
 National University of  
 Sciences and Technology,  
 Pakistan

Zainab Nisha Khan (Author)  
 National University of  
 Sciences and Technology,  
 Pakistan

permittivity of free space,  $W$  is the width of resonator and  $t$  is the gap of resonator.

Two microwave techniques are used for characterization of material, one is non-resonant technique and other is resonant technique. Method that can measure over the wide range of frequencies is the non-resonant method while resonant method works on discrete frequencies. Resonant method has an advantage over non-resonant method due to its low uncertainty and higher precision, moreover it is suitable for small size sample [4]. In this study, change in  $Q$  and  $f_r$  have been obtained using non planar structures [6].

In earlier studies it has been shown that when a material is placed in resonator gap, resonant behavior of SRR changes. Shifts in  $Q$  and  $f_r$  are due to unique set of permittivity values of materials being introduced in resonator gap. Shift in resonant behavior remains fixed for the SRR structure though it may differ from structure to structure. Larger shift in resonant property results in high sensitivity and thus can be used for high sensitive characterization like compositional analysis of polar liquids [3]. In order to produce varying resonant behavior, a novel structure namely dual split ring resonator (DSRR) is being proposed. This structure utilizes two SRRs which are placed at a certain distance. Varying behavior is obtained by changing the distance of two SRRs employed. Four different materials i.e. glass, mica, rubber and plastic are placed within resonator gap to produce four sets of varying resonant behavior. This paper analyzes and compares resonant behavior of conventional SRR [9] with DSRR.

## II. Theory

SRR is considered as lumped element circuit where electric field is maximum inside the gap and magnetic field is maximum at the other end of the metallic cylinder. Resonator is enclosed in conducting shield to improve the  $Q$  and to reduce radiation losses [10].  $Q$  and  $f_r$  are influenced by shield and resonator dimensions.  $f_r$  of the resonator is defined as:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad (3)$$

Where  $L$  is the inductance and  $C$  is the capacitance. Similarly, the  $Q$  of resonator material is defined as:

$$Q = \omega_0 \frac{U}{P_L} \quad (4)$$

$$Q = \frac{f_r}{BW} \quad (5)$$

Where  $f_r$  is the resonant frequency,  $BW$  is the bandwidth,  $\omega_0$  is the angular frequency,  $U$  is the electromagnetic energy and  $P_L$  is the average dissipation of energy in resonator.

When a material is introduced in the gap of resonator where electric field is maximum, perturbation of field results in shifts in  $Q$  and  $f_r$  of the resonator. From these changes in resonant behavior, relative permittivity can be attained [11, 12]. It is necessary for an unperturbed system to produce high  $Q$  in order to produce less power dissipation.

Perturbation theory is used to find permittivity [7]. Permittivity is composed of real and imaginary part and is given by:

$$\varepsilon^* = \varepsilon_0 \varepsilon_r^* \quad (6)$$

$$\varepsilon_r^* = \varepsilon_r' - j\varepsilon_r'' \quad (7)$$

$$\frac{f_1 - f_2}{f_2} = A(\varepsilon_r' - 1) \frac{v_s}{v_c} \quad (8)$$

$$\frac{1}{Q_2} - \frac{1}{Q_1} = B(\varepsilon_r'') \frac{v_s}{v_c} \quad (9)$$

$\varepsilon_r'$  represents energy storage property of material, whereas  $\varepsilon_r''$  represents loss of energy in material.  $f_1$  is the resonant frequency without material and  $f_2$  is the resonant frequency after placing material into a gap.  $A$  and  $B$  are constants,  $v_s$  and  $v_c$  are volume of shield and resonator.  $Q_1$  and  $Q_2$  are the quality factors with and without material insertion. From the equation we see that change in  $Q$  is inversely proportional to  $\varepsilon_r''$  and change in  $f_r$  is directly proportional to  $\varepsilon_r'$ . Rearranging (8) we get  $\varepsilon_r'$  as shown in (10):

$$\varepsilon_r' = k_1 \left( \frac{f_1 - f_2}{f_2} \right) \quad (10)$$

Where ( $k_1 = \frac{v_c}{A*v_s}$ ). Similarly rearranging (9) to get the complex part of permittivity  $\varepsilon_r''$  as shown in (11):

$$\varepsilon_r'' = k_2 \left( \frac{\Delta Q}{Q_2 * Q_1} \right) \quad (11)$$

Whereas ( $k_2 = \frac{v_c}{B*v_s}$ ).  $\Delta Q$  is the change in  $Q$ . From these equations one can easily find out the values of permittivity of the material [12].

## III. Design and Simulation

### A. Split Ring Resonator (SRR)

Design and simulation of conventional SRR was carried out in HFSS version 13.0. Copper was used for SRR due to its high conductivity. Resonator was enclosed in aluminum shield in order to get minimum losses and high  $Q$ . Shape and design parameters of SRR using HFSS 13.0 are shown in Fig. 2 and table I:

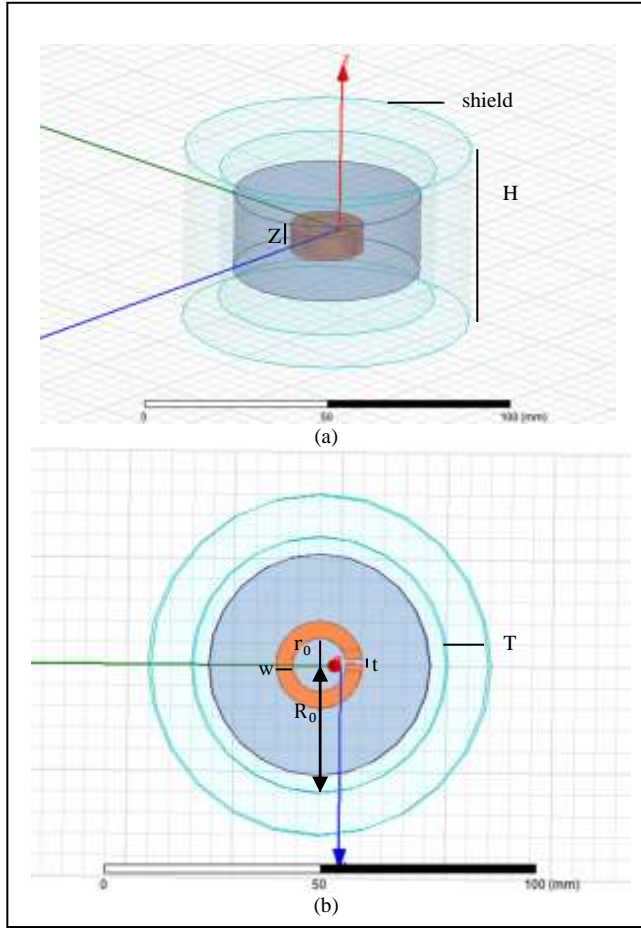


Figure 2. (a) SRR within a shield (b) SRR Top view

TABLE I. STRUCTURAL PARAMETERS OF SRR

Parameters	Sizes
Inner Radius of Shield ( $R_0$ )	30mm
Inner Radius ring ( $r_0$ )	6.3mm
Width of ring ( $w$ )	3.9mm
Width of shield ( $T$ )	10mm
Length of ring ( $Z$ )	5mm
Length of shield ( $H$ )	50mm
Gap of ring ( $t$ )	1mm

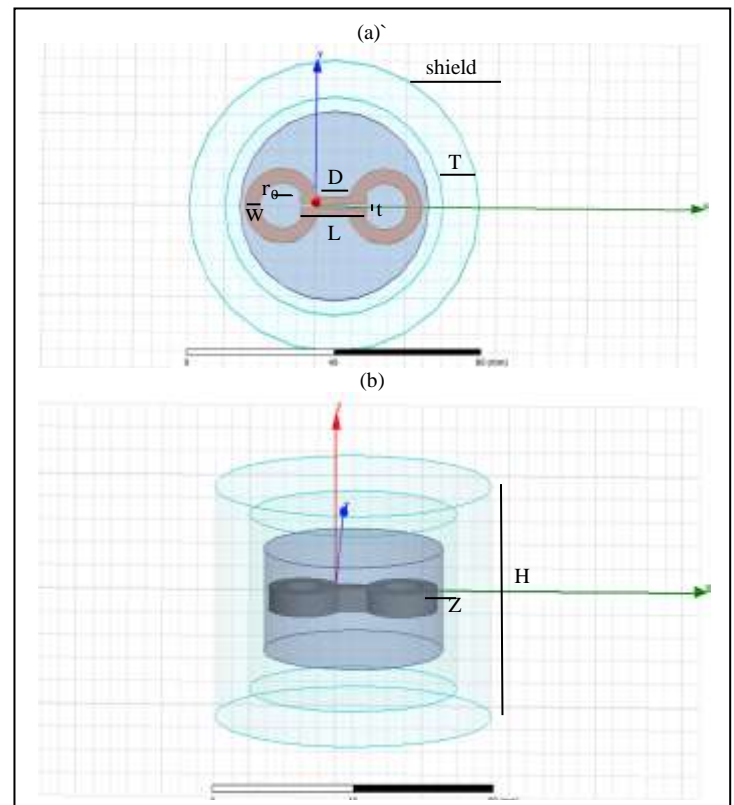
Initially behavior of resonator is observed without insertion of any material inside gap. Then the material having different permittivity was introduced within a resonator gap. Four dielectric material as mentioned earlier, were introduced inside the gap of resonator. In each case, shift in the  $f_r$  and  $Q$  was observed. These values are shown in table II.

TABLE II. RESONANT FREQUENCY AND QUALITY FACTOR OF SRR

Material inside resonator gap	$f_r$ (GHz)	$Q$
Air	2.1	2293
Glass	1.7	1981
Mica	1.69	1975
Rubber	1.92	2104
Plastic	1.89	2090

### B. Dual Split Ring Resonator (DSRR)

SRR was modified to achieve high sensitivity of resonator and to produce the variable  $f_r$  and  $Q$ . For this purpose DSRR was designed. Two SRR were combined with a metal strip to make DSRR. The whole structure represents inductance whereas the gap between metal strips represents capacitance. By changing the distance ( $D$ ) between two SRR,  $f_r$  and  $Q$  can be changed. Length of metal strip was set to the constant value. Optimized design was obtained showing optimum results. Variable  $f_r$  and  $Q$  is obtained as shown in table IV and table V. Shape and design parameters of DSRR using HFSS 13.0 are shown in Fig. 3 and table III.



Distance Distance (D)	Material				
	Air	Glass	Mica	Rubber	plastic
	$Q$	$f_r Q$	$f_r Q$	$f_r Q$	$f_r Q$
	GHz	GHz	GHz	GHz	GHz
0mm	2168	1763	14822	12077	12030
2mm	2228	1860	15225	12121	6.3mm 152
4mm	1399	1929	12033	12338	12349
6mm	1399	1929	12033	12338	3.9mm 1333
8mm	3780	2611	12104	12400	12412
10mm	3926	2696	12192	12406	40mm 1219

Length of length of both rings (Z)	5mm
Length of shield (H)	50mm
Gap of Resonator (t)	1mm
Length of metal strip (L)	18mm
Distance between the rings (D)	0 to 10 mm

Figure 3. (a) DSRR Top view (b) DSRR inside shield  
 TABLE III. STRUCTURAL PARAMETERS OF DSRR

Initially behavior of resonator was observed by changing the distance between two SRRs without insertion of any material inside gap. Then shift in  $f_r$  and  $Q$  was observed at different values by changing D and dielectric material. Below are the results of  $f_r$  and  $Q$  shown in tabular form.

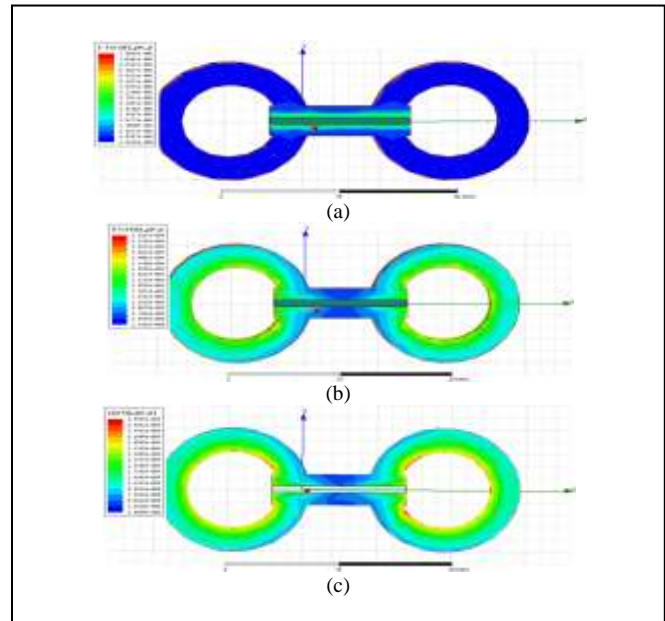
TABLE IV. RESONANT FREQUENCY OF DSRR

TABLE V. QUALITY FACTOR OF DSRR

Furthermore, plots of current distributions, electric and magnetic field distributions in the ring at each resonant frequency were made; at  $f_r$  plot shows lowest and highest values of current, electric and magnetic fields in the structure as shown in Fig. 4.

Figure 4. (a) Electric field (b) Magnetic field. (c) Current distributions at  $f_r$  of 1.67 GHz

## iv. Analysis and Discussion



### A. Resonant Frequency

Four materials have been placed inside the gap of the resonator in both designs. Results were obtained for sensitivity analysis. Graphical analysis of both structures indicate that the conventional yielded fixed value of  $f_r$  and  $Q$  whereas variable  $f_r$  and  $Q$  were generated with DSRR when distance between rings SRR was varied. Fig. 5 and Fig. 6 shows  $f_r$  comparison of SRR and DSRR. Sensitivity analysis has been obtained for DSRR by changing the distance between two rings. It can be observed that as the distance between the rings keeps on increasing  $f_r$  of the DSRR changes accordingly.

Figure 5. SRR resonant frequency

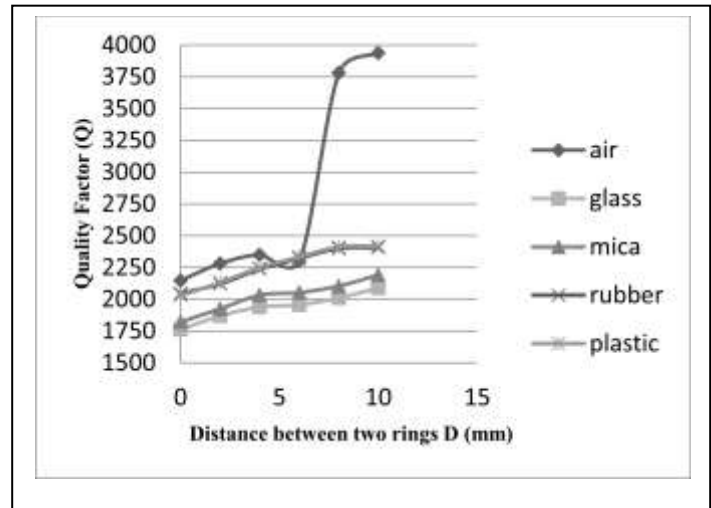
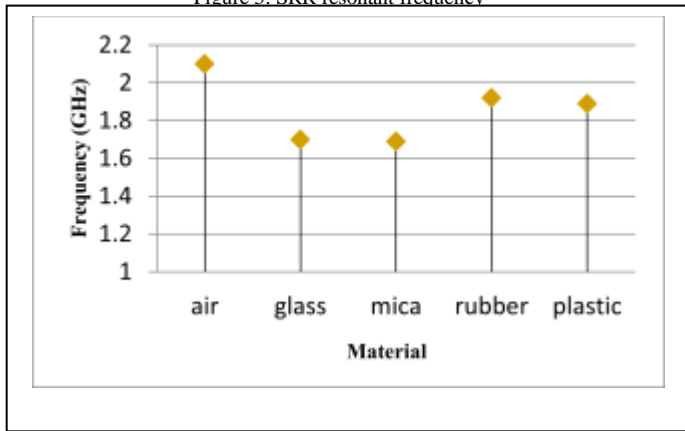
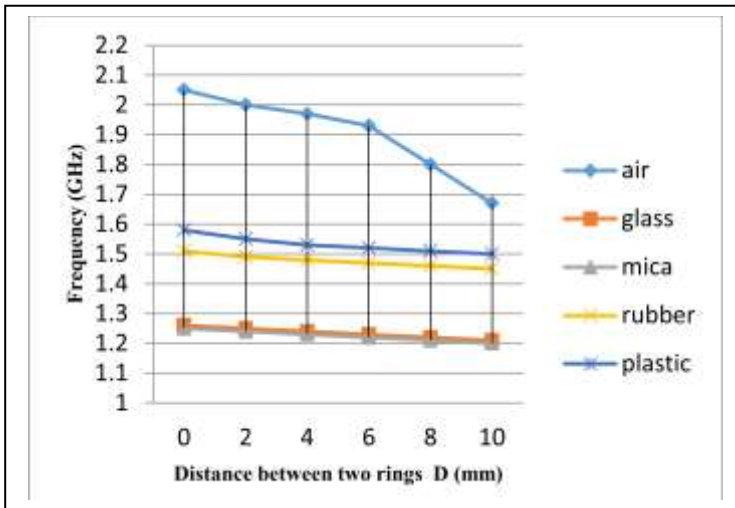


Figure 7. SRR quality factor

Figure 8. DSRR quality factor

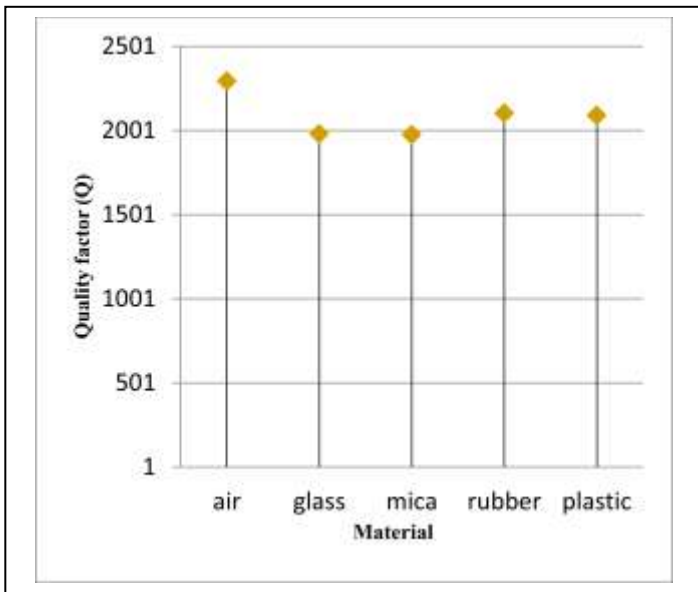


## v. Conclusion

DSRR with optimum design have been proposed in this paper. Proposed design is compared with SRR on the basis of  $Q$  and  $f_r$ . Conventional SRR yielded fixed value of  $f_r$  and  $Q$  whereas variable  $f_r$  and  $Q$  were generated with DSRR. Hence Different sets of shifts in resonant properties were obtained with DSRR. In addition to that DSRR has maximum shift in the resonant behavior as compared to SRR. It could be concluded that proposed design work over variable  $f_r$  and  $Q$  and is highly sensitive unlike SRR.

### B. Quality Factor

Sensitivity analysis of DSRR has also been obtained in a similar fashion.  $Q$  was observed while the distance between two rings of DSRR was changed. It can be observed that as the distance between the rings keeps on increasing the  $Q$  of the DSRR changes accordingly. Fig. 7 and Fig. 8 shows the  $Q$  comparison of SRR and DSRR.



### References

- [1] T. Ejaz, H. U. R. Khawaja, A. Masood, T. Zaidi, and M. Naveed, Modeling of Compositional Analysis for Liquid Solvents in Microfluidic Channel Using Split Ball Resonator, 2016.
- [2] M. Mehdizadeh, T. Koryu Ishii, J. Hyde, and W. Froncisz, Loop-Gap Resonator: A Lumped Mode Microwave Resonant Structure vol. 31, 1983.
- [3] R. Göritz, A. Masood, O. Castell, D. A. Barrow, C. Allender, and A. Porch, Microwave Compositional Analysis of Solvent Matrices in Microcapillary Manifold Systems, 2007.
- [4] A. Schönhals and F. Kremer, "Broadband Dielectric Measurement Techniques (10-6 Hz to 10<sup>12</sup> Hz)," in Broadband Dielectric Spectroscopy, F. Kremer and A. Schönhals, Eds., ed Berlin, Heidelberg: Springer Berlin Heidelberg, 2003, pp. 35-57.
- [5] H. Choi, J. Naylor, S. Luzzio, J. Beutler, J. Birchall, C. Martin, et al., Design and In Vitro Interference Test of Microwave Noninvasive Blood Glucose Monitoring Sensor, 2015.
- [6] T. Ejaz, H. U. R. Khawaja, S. Shah, and T. Zaidi, A Comparative Analysis of Split-Ring Resonator Models, 2015.
- [7] O. Sydoruk, E. Tatartschuk, E. Shamonina, and L. Solymar, Analytical formulation for the resonant frequency of split rings vol. 105, 2009.

- [8] W. Froncisz and J. S. Hyde, "The loop-gap resonator: a new microwave lumped circuit ESR sample structure," *Journal of Magnetic Resonance* (1969), vol. 47, pp. 515-521, 1982/05/01/1982.
- [9] M. Younis, T. Ejaz, T. Zaidi, and H. U. R. Khawaja, *Modified Split Ring Resonator with Enhanced Permittivity Sensitivity*, 2019.
- [10] M. Mehdizadeh and T. K. Ishii, "Electromagnetic field analysis and calculation of the resonance characteristics of the loop-gap resonator," *IEEE Transactions on Microwave Theory and Techniques*, vol. 37, pp. 1113-1118, 1989.
- [11] T. Ejaz, H. U. Rahman, T. Zaidi, T. Tauqeer, and S. A. A. Shah, "Analysis, simulation, and experimental verification of split-ring resonator," *Microwave and Optical Technology Letters*, vol. 57, pp. 2358-2363, 2015.
- [12] T. Hayat, T. Ejaz, M. Naveed, T. Zaidi, and H. U. R. Khawaja, *Permittivity sensing and measurement with novel split ball resonator using E-field perturbation technique* vol. 60, 2018.

About Author (s):



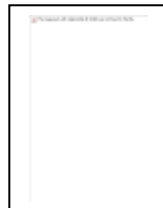
**Hina Imtiaz** received her B.S. degree in Electronics Engineering from International Islamic Islamabad, Pakistan. At present, she is pursuing her Masters in Electrical Engineering from College of Electrical and Mechanical Engineering, National University of Sciences and Technology, Pakistan. Her area of research is microwave resonators



**Tahir Ejaz** received his Ph.D. from College of Electrical and Mechanical Engineering, National University of Sciences and Technology, Pakistan in Electrical Engineering. At present, he is serving as Assistant Professor at HITEC University, Pakistan in Electrical Engineering Department.



**Tahir Zaidi** received his Ph.D. in computer semiconductors from Georgia Institute of Technology, School of Electrical and Computer Engineering, USA. At present, he is serving as Professor at College of Electrical and Mechanical Engineering, National University of Sciences and Technology, Pakistan in Electrical Engineering Department.



**Zainab Nisha Khan** received her B.S Electrical Engineering degree from COMSATS University, Pakistan. Currently, she is pursuing her Masters in Electrical Engineering from College of Electrical and Mechanical Engineering, National University of Sciences and Technology, Pakistan.