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Dielectric Properties Measurement Using Ring Resonator

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Abstract: ***This paper gives an idea of determining electrical properties of a material using simple ring resonator. Here, the radiating element is a ring resonator. The ring resonator with sufficient coupling gap is designed and simulated in HFSS software and observed S parameters. After designing a ring resonator, the layer of aqueous glucose with different known dielectric constants is deposited on the ring covering coupling gap and again analyzed and finally observed the shift in resonant frequency. The simulation result shows that, the resonant response of the sensor changes as per the change in permittivity of aqueous glucose.***

Keywords: ring resonator, insertion loss (S21), coupling gap, dielectric constant

1. Introduction

Every material has a unique set of electrical characteristics that are dependent on its dielectric properties. So if these measurements are accurate then it can provide scientists and engineers with valuable information to properly use a material into its specific application from high speed circuits to satellite and telemetry applications.

There are different methods of dielectric properties measurements like coaxial probe method, free space method, resonant methods etc., but resonant methods are most widely used than non-resonant ones. The resonance methods do not have sweep frequency capabilities for the measured frequency range. Also, these resonance techniques are more accurate than any other techniques for very low loss materials. Resonators have possible high Q-factor and results in very high sensitivity. So these resonators can be used as sensors of different physical quantities which depend upon dielectric constant i.e. complex permittivity of MUT (Material Under Test).

In this paper, the dielectric constant of aqueous glucose samples with different concentrations is found out using basic ring resonator as a sensor. There is a shift in resonant frequency of a resonator when a sample and microwaves interact with each other. This shift in frequency is nothing but dielectric constant of that material or sample.

2. Literature Survey

Several techniques were invented by different researchers to measure dielectric constants of any material. These days researchers are using resonance techniques for material characterization. Muhammad Taha Jilani et. al. designed a ring resonator for the measurement of dielectric constant of meat [1].

A. Kumar, G. Singh found out a new technique to measure dielectric constant using rectangular shaped cavity [2]. Surendar R developed a method to find out dielectric characterization using meander resonator sensor. This sensor was implemented using planar microstrip technique and the materials are characterized using curve fitting method [3]. M. S. Kheir, et. al. developed a hybrid cavity-ring resonator for estimating dielectric constants of liquids. In this, the waveguide cavity acts as metallic enclosure for the ring circuit [4].

Sushanta Sen, et.al. developed a technique of cavity perturbation for estimating electrical parameters of a material. This method involves the modified cylindrical cavity which was suitable for low dielectric materials only [8]. Serhan Yamaeli, Ali akdagii presented a technique for determining dielectric constant of microwave PCB substrates. In this method, a bandpass microstrip filter was used and designed on PCB substrate [6].

For measuring the moisture content and dielectric constant of soil, Komal Sarabandi et. al. developed a microstrip ring resonator. Here they placed the resonator between the soil content and thus determined the value of pemittivity by measuring S parameters and Q-factor [9]. Sompain Seewathanopon also developed a microstrip ring resonator for dielectric constant measurement [7].

3. Ring Resonator Method

3.1 Structure of Ring Resonator

Ring resonator is used to determine the complex permittivity of any material. This structure consists of transmission lines and a ring on a substrate. The feed lines and ring resonator are printed transmission lines with width chosen for 50 Ω characteristic impedance. There is a small coupling gap of Δ between these transmission lines and a ring. This gap is included to separate the resonant behavior of the ring from the feed network and ranges from 0.1 to 1.0 times the width of the feed microstrip. The structure of ring resonator is shown in figure 1.

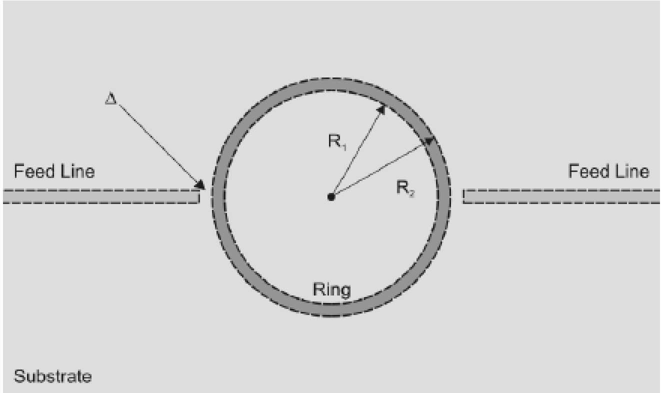

Figure 1: Planar Ring resonator structure

3.2 Design of Ring Resonator

Ring resonator is designed on a PCB substrate of FR4 having dielectric constant (ε_r) of 4.4.These resonators satisfy the resonance condition of:

$$2\pi R = n\lambda_g \text{ for n=1,2,3} \quad \text{........ (1)}$$

Here, R is the mean radius of the ring and n is the harmonic order of resonance.
Guided wavelength is calculated by using following relation:

$$\lambda_g = \frac{c}{\sqrt{\varepsilon_{eff}}\, f} \quad (2)$$

Here, c is the velocity of light, f is the resonant frequency, λ_g is the guided wavelength and ε_{eff} is the effective dielectric constant and it is given by the relation of:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \times \frac{1}{\sqrt{1 + 12\frac{d}{w}}} \quad (3)$$

Where, ε_r is relative dielectric constant, w is the width of ring and d is the substrate thickness.
Feed line (transmission line) length is computed using following relation:

$$\text{Feed line length} = \frac{\lambda_g}{4} \quad (4)$$

Inner and outer radius of the ring are computed by subtraction and addition of half of width of microstrip to the mean radius resp. It is given by,

Inner radius: $R_i = R - \frac{w}{2}$ (5)

Outer radius: $R_a = R + \frac{w}{2}$ (6)

Coupling between the feed line i.e. transmission line and the ring is taken into account as it has capacitance and its effect can change the resonant frequency. It is very important to understand that if the coupling gap is too large of 0.8mm then it causes more insertion loss and if the coupling gap is too small of 0.1mm then it causes more shifts in resonance [10]. So coupling gap should be as moderate as possible i.e. between 0.2mm to 0.4mm. In this research work, gap is taken as 0.2mm for better performance. Different dimensions of resonator are given in the tabular format as follows:

Table 1: Dimensions of Ring resonator

Parameters	*Values*
Width of feed line	1 mm
Feed line length	42.86 mm
Coupling gap	0.2 mm
Total length of substrate	141.7 mm
Total width of substrate	115 mm
Inner radius of ring	26.79 mm
Outer radius of ring	27.79 mm
Substrate used	FR4

3.3 Multilayer Ring resonator

In this research work, multilayer ring resonator is simulated. This multilayer contains the aqueous glucose solution with different concentrations of glucose in water. The proposed design of a multilayer configuration of ring resonator is depicted in figure 2 [1].

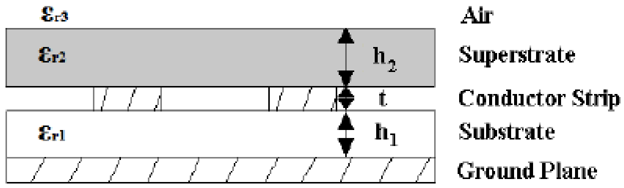

Figure 2: Structural view of a proposed multilayer ring resonator

4. Designing of Ring resonator and Multilayer ring resonator in HFSS

4.1 Designing of Ring resonator in HFSS

Ring resonator with the dimensions given in table 1 is designed and simulated in ANSYS HFSS software. This resonator is designed at resonating frequency of 1GHz. First the resonator is designed and simulated without MUT (Material under Test) and observed the simulated results and then multilayer ring structure with different aqueous glucose concentrations is simulated in HFSS. Following figure 3 shows design of ring resonator without MUT.

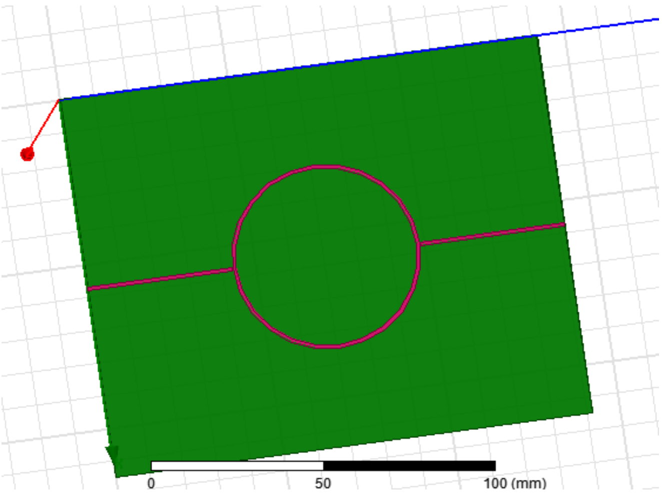

Figure 3: Designing of ring resonator in HFSS

4.2 Designing of Multilayer Ring resonator in HFSS

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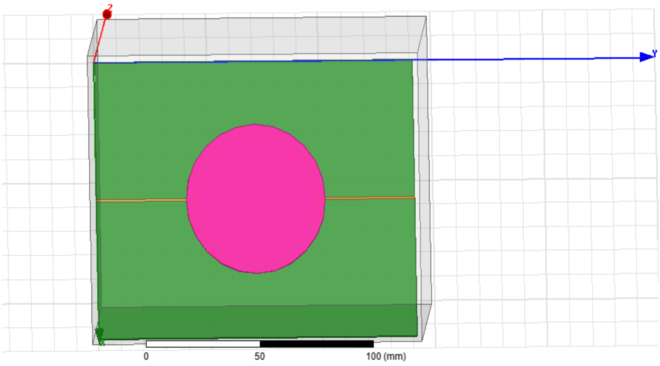

Figure 4: Designing of multilayer ring resonator in HFSS

To study the dielectric properties of aqueous glucose with different concentrations, 1GHz ring resonator is designed in HFSS software. Initially, simulation results were obtained for un-loaded resonator i.e. (without any overlay-dielectric). After that, for loaded resonator, a sample is placed over ring-resonator as shown in figure 4. Dielectric constants of these samples are known and are taken from literature [5]. A disc-shape sample covering coupling gap and radius more than that of ring is placed on the top of ring (shown in Fig.4). Placement of sample above the ring is 1mm. Dielectric constants for different concentrations of aqueous glucose is given in table 2. Taking the known dielectric constants for simulation, we observed the frequency shifts and results are recorded.

Table 2: Dielectric constant variations

Weight percent of glucose in water	*Dielectric constant at* 25^0C
0	78.54
5	77.37
10	76.14
15	74.80
20	73.43
30	70.46
40	67.11
50	63.39

5. Results and Discussion

For measuring dielectric constants in this work, ring resonator as a sensor has been designed and simulated in HFSS. Simulation result of ring resonator without MUT is shown in figure 5. First resonance occurs at 0.944GHz with S21 of -8.22dB. Then second , third, resonances at 1.8GHz , 2.81GHz with S21 of -6.40dB and -3.52dB and so on. Taking the MUT as different aqueous glucose solutions with dielectric constants as shown in table 2, we observed the frequency shifts and these shifts are given in table 3.

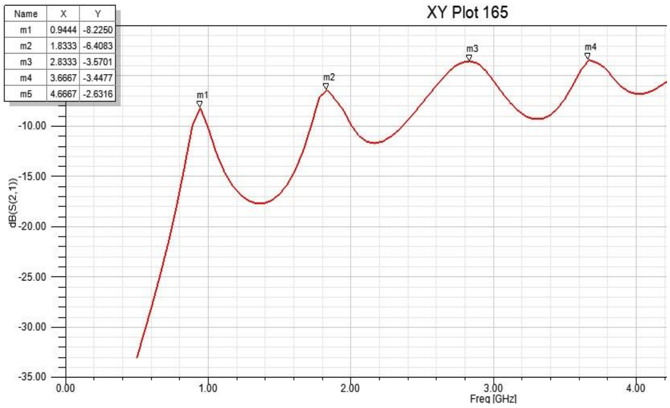

Figure 5: S21parameter from HFSS simulation of ring resonator without MUT with periodic resonances

Table 3: Relation between aqueous glucose concentration and frequency shift

Wt. % of glucose in water	*Frequency shift in GHz*
0	0.1
5	0.1667
10	0.3334
15	0.6112
20	0.5556
30	0.6667
40	0.6112
50	0.6888

Following figure 6 shows the graph of frequency shifts as dielectric constant changes when weight percent of glucose in water changes**.**

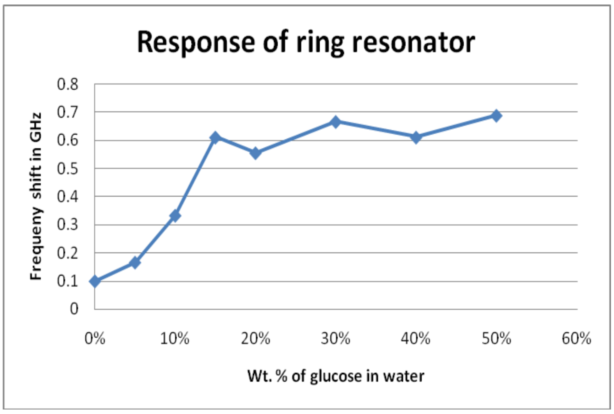

Figure 6: Wt. % of glucose Vs Frequency shift

6. Conclusion and Future Work

A simple ring resonator as a sensor is designed and simulated in HFSS software. The geometrical parameters are optimized to attain the best electromagnetic properties. This sensor operates at 1GHz frequency and shows good insertion loss which occurs at -8.26dB. Also there is a shift in frequency as aqueous glucose concentration changes due to change in dielectric constant. This shows that a ring resonator can be used as a sensor. Impending opportunity of this paper will be designing a sensor which should be able to detect these changes , without making direct contact to blood i.e. for non-invasive blood glucose monitoring. It would be a glucometer that the diabetics can use on the body on daily basis.

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