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Dielectric Characterization using Meander Resonator sensor

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Abstract — **Measurement of dielectric constant using microstrip meander resonator sensor for a material under test is proposed. The resonant characteristics of resonator vary with dielectric constant of material. The sensor is implemented using planar microstrip technology. Using curve fitting method the relative dielectric constant of the MUT was obtained. The proposed resonator was designed using ADS for a fundamental frequency of 1 GHz and has great potential for practical applications in view of low cost.**

***Index Terms*—MMR sensor, Permittivity, Curve Fitting, Resonant frequency.**

I. Introduction

DIELECTRIC constant of any material is an important parameter to be considered for numerous applications[1]-[4] in various field. For this different kind of microwave sensors are deployed to study the electromagnetic radiation of microwave region. Microwave dielectric measurement methods are of two types, namely resonant and non-resonant methods. Where resonant methods have relatively higher accuracy than the non-resonant ones. In resonant methods, the material under test is introduced to a resonator thus altering the electromagnetic boundaries of the resonator, and the electromagnetic properties of the sample are deduced from the change of the resonant properties of the resonator. Due to its high accuracy and its flexibility in sample preparation, the resonant method is widely used for low-loss samples, powders, small size samples and samples of irregular shapes.Different applications require different sensors and they are developed for particular applications.

Resonators are commonly used as precise instruments for electromagnetic properties of materials such as complex permittivity, permeability and the surface resistance at microwave frequencies. For very low loss materials the resonant technique is the only one enabling measurements with sufficient accuracy. Due to possible high Q-factor of the resonators, and resulting very high sensitivity, such resonators can be also used as sensors of different physical quantities that depend on complex permeability of a material under test. During the recent decades resonators are deployed for complex measurements of materials at microwave frequencies. At present dielectric resonators are frequently used for measurements of dielectric materials, ferrites and super conductors at microwave frequencies.

Even though resonator sensors are deployed for dielectric measurements, they are also used for measuring humidity, chemical reactions and paramagnetic impurities. The main advantages of resonators used as sensors are; easy to design, build and operate at various distinguished microwave frequencies. Also has high precision level and high Q-factor

Resonant methods have relatively higher accuracy than non-resonant ones. For measurement, the sample is introduced into a resonator thus altering the electromagnetic boundaries of the resonator, and the electromagnetic properties of the sample are deduced from the change of the resonant properties of the resonator. Due to its high accuracy and its flexibility in sample preparation, the resonant method is widely used for low-loss samples, small size samples and samples of irregular shapes. In sensors structure, the sensors based on waveguide and coaxial lines are bulky and are not convenient for integration with electronic circuits. Planar transmission lines are used in order to develop compact sensors. The planar resonator structure is very simple, low cost, and easy to remove samples. Several investigators have used microstrip resonators for determination of dielectric constant of materials. The dielectric constant can be computed by using a resonant frequency shift.

In this paper the dielectric constant of Olive Oil is found out using meander resonator as a sensor. The mechanism adopted for the determination of permittivity is the relative shift in resonant frequency which takes place when microwave interacts with the sample. A calibration equation relating the measured shift in resonant frequency for different modes and the dielectric constant has been found.

II. RING RESONATOR

The ring resonator structures have been utilized in different electromagnetic measurements. Advantages of the ring resonator structure compared to linear planar transmission line resonators are the absence of end-effects and higher values of quality factor. On the other hand, effects of curvature of the conductor line and effects of coupling gaps must be taken into account in the design of the ring resonator. Although the microstrip line configuration is the most commonly used

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approach for dielectric measurements, the strip line ring resonator has also been employed.

With the two-port ring resonator structure a better signal to noise ratio can he achieved and the dissipation factor of material can be determined, thus the two-port ring resonator is often preferable structure. The two-port ring resonator structure includes feed lines, a closed transmission line loop and coupling gaps. The function of the two-port ring resonator is based on simple equation

$$2\pi r = n\lambda g \qquad (1)$$

Where r is a mean radius of the ring and n is the positive integer (1,2,3…), and λg is guided wavelength. Usually in dielectric properties measurements frequency response of the two-port ring resonator structure is measured with a network analyzer. The unwanted effects of connector interfaces of the ring resonator structure, have to be eliminated for example by a thru-reflect-line (TRL) calibration. Basing on the measured frequency response and can be values of effective permittivity calculated in function of frequency. The dielectric constant can be calculated basing on the frequency dependent value of the effective permittivity. Losses of material can he also calculated based on the measured frequency response of the ring resonator. In order to get reliable measurement results, the effects of coupling gaps have to be known or eliminated. In addition, the mean radius of the ring and characteristic impedance of the ring resonator, have to be chosen to be suitable to eliminate curvature effect and higher order modes.

The coupling gaps have an influence to the resonance frequencies of the ring resonator structure. Normally coupling between the feed lines and the ring resonator are tried to implement with loose coupling. The loose coupling produces negligible effects to the resonance frequencies. Suitable length for the coupling gaps has to be chosen by using prototypes or modem electromagnetic simulation tools. The effects of the different lengths of coupling gaps are minor to determined values of dielectric constant and dissipation factor, if the coupling is implemented loose.

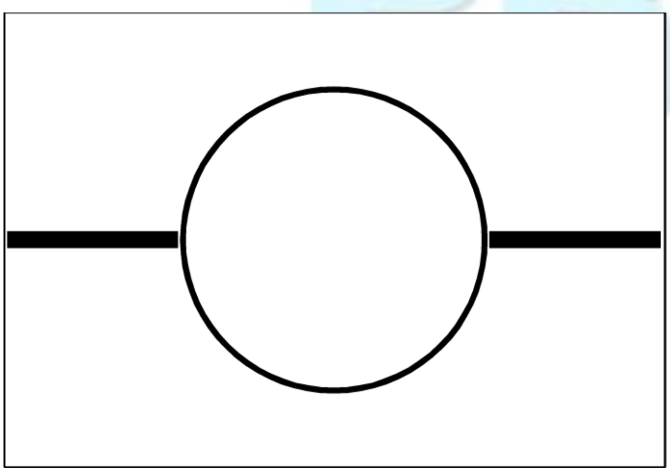

Fig.1 Structure of Ring Resonator

III. MEANDER RESONATOR

Meander is termed generally which has many courses of bends in its path. As a resonator, these are widely deployed for various applications [5]. Mostly used in filter circuits for respective pass bands. Also various other industrial applications in view of measurements are using these types of resonators.

The base for this design is microstrip ring resonator, from which the meander structure is derived with set of basic design equations. The meander resonator consists of symmetrically located input/output, microstrip feed lines, coupling gaps, and a microstrip line of one wavelength. The microstrip ring resonator uses a big size of samples, while meander sensor is more suitable for a small area of Dielectric under test (DUT).

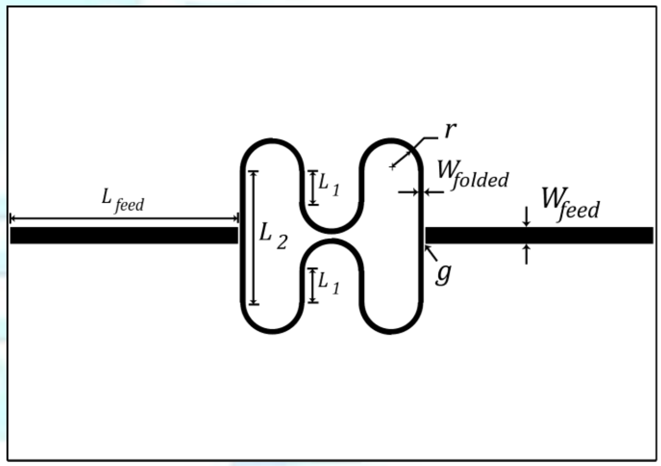

Fig.2 Structure of Meander Resonator

IV. COMMON DESIGN PARAMETERS FOR RING AND MEANDER RESOANTOR

A substrate of FR4 (ε_r= 4.6) has been used for both the resonators with the dielectric thickness of 0.762 mm, resulting into following Coupling parameters: feed length = 40mm, gap = 0.35mm, Substrate thickness = 1.6mm, Microstrip line width = 1mm and total resonator length = 170mm. Generally the microstrip resonator length is found out by the following equations (2) and (3).

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \qquad (2)$$

Where

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\left(1 + 12\left(\frac{h}{w}\right)\right)^{\frac{1}{2}} + 0.04\left(\left(1 - \frac{w}{h}\right)\right)^2\right] \qquad (3)$$

V. COMPARISON BETWEEN RING AND MEANDER RESONATOR

Fig.1 illustrates a schematic of the microstrip ring resonator. The resonator responses have been determined by a vector network analyzer and the resonant frequency is designed at 1GHz. The radius of the ring resonator is 26.5 mm. The strip width of ring resonators is 1.6 mm and the coupling gaps are 0.35 mm. For each mode the peak points of insertion loss S_{21} are recorded.

Parameter	Ring resonator	Meander resonator
Value of S12 simulated with air as dielectric constant	Freq= 1 GHZ, S12 = -11.935 dB	Freq= 1 GHz, S12 = -8.39 dB
Value of S12 simulated with Olive oil as dielectric constant	Freq= 874 MHz, S12 =-5.082 dB	Freq=908 MHz, S12=-4.627 dB
Area in mm	2206sq. mm	1138 sq.mm
Substrate used	FR4	FR4
Thickness of dielectric Slab in mm	1.6 mm	1.6 mm

The meander in Fig.2 has also been designed at the same 1 GHz frequency and has a compact size when compared with ring resonator. The proposed resonator layout with all dimensions is shown in Fig.2. *Wfeed*=2.95mm, *Lfeed*= 40mm, *L1* =5.64mm, *L2* = 23.52mm, r = 5mm ,coupling gap *g* = 0.35mm. and Z_o =50 ohms..The physical area of the meander shaped resonator is reduced by 51.58% of the area of the ring resonator.

Table.1 Comparison between ring and meander simulations
Dielectric constant of Air = 1,
Dielectric constant of Olive oil = 3.1
Placement of dielectric (Olive oil) above the Microstrip is 10 mm.

Table.1 shows the detailed comparisons between the ring resonator and the meander resonator. The area is subsequently reduced in the meander resonator.

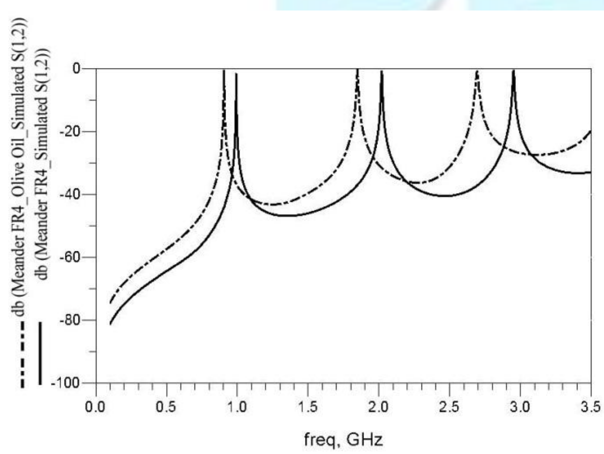

Fig.3 Simulated output for Meander

Fig.3 and Fig.4 shows the simulated and measured response curves for both air as dielectric and Olive oil as dielectric are obtained. From which the values are used for curve fitting using varied modes and respective frequency shift.

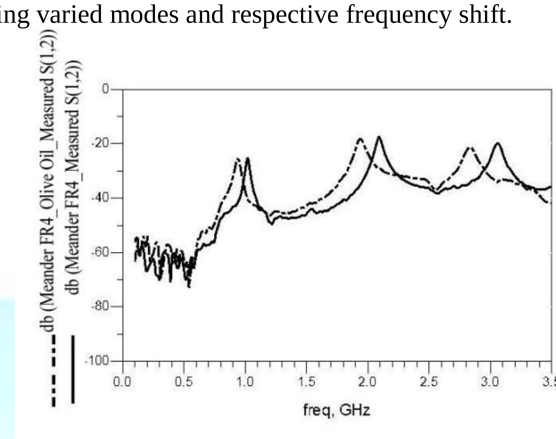

Fig.4 Measured output for Meander

VI. SIMULATED AND MEASURED RESULT

Resonator Type	Dielectric	Resonant frequency(simulated) GHz			Insertion Loss (Simulated) dB		
Meander	Air	1	2	3	0	0	0
	Olive oil	.887	1.81	2.63	0	0	0

Table 2. Simulated Result

Resonator Type	Dielectric	Resonant Frequency(Measured) GHz			Insertion Loss (Measured) dB		
Meander	Air	1.05	2.1	3.01	-26	-18	-19
	Olive oil	.938	1.938	2.838	-25	-18	-21

Table 3. Measured Result
Dielectric constant of Air = 1,
Dielectric constant of Olive oil = 3.1
Placement of dielectric (Olive oil) above the Microstrip is 10 mm.

VII. DETERMINATION OF DIELECTRIC CONSTANT

A sample of the MUT is placed over the meander sensor. The shift in the resonant frequency is recorded by connecting the sensor with a vector network analyzer. The VNA which works as exciting source is connected with two feeding probes of the sensor. The signal from the network analyzer is coupled via coaxial cable which connects two ports of the VNA to the sensor probes. The frequency response of the reflected signal is displayed in the network analyzer. From the shift in resonant frequency, dielectric constant of any material can be calculated from the following polynomial equation generated using curve fitting method.

$$\varepsilon_r = 1103.8 - 109.5x + 18x^2 - 1.5x^3 \quad \text{.... (3)}$$

Where x = Shift in resonant frequency

Taking the known dielectric constants for simulation, firstly different node at varied frequencies are simulated. The values of each nodes are plotted and that gives a curve with frequencies and equivalent dielectric constants through which the measured frequency of a material can be matched with its dielectric constant.

Dielectric Constant	Mode 1 (GHz)	Mode 2 (GHz)	Mode 3 (GHz)
1	1.012	2.017	3.005
2	0.94	1.918	2.803
3	0.904	1.805	2.691
4	0.853	1.743	2.526
5	0.82	1.678	2.422

Table.4 shows the frequency shift between three different modes varying with the respective dielectric constants. Fig.5 shows the frequency shift to the relative dielectric constant.

Table 4. Dielectric constant Vs Frequency for Meander resonator

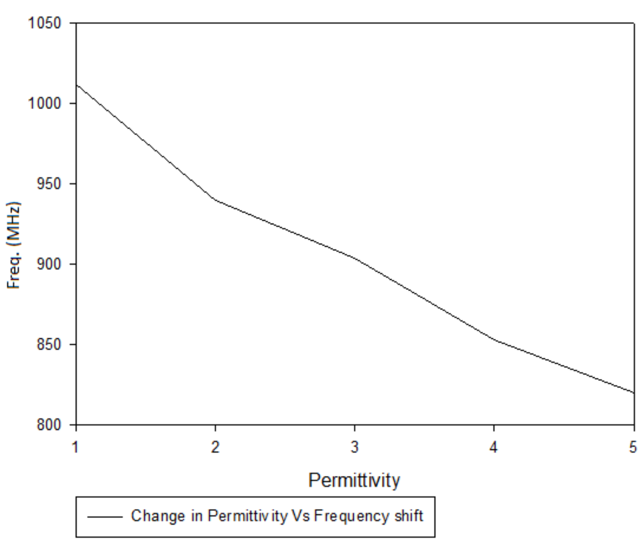

Fig.5 Dielectric Constant vs. Relative shift in frequency

VIII CONCLUSION

For determining dielectric constant of materials, the meander resonator sensor based on a microstrip ring resonator structure has been analyzed and compared. The proposed resonator sensor has been simulated, resulting in formulation of dielectric constant equations for DUT. The proposed sensor has high performances with low cost, small volumetric measure and simplicity for manufacturing; therefore, it may be useful for measurement of dielectric constant of many kinds of materials with known dielectric values using curve fitting method.

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