EXPERIMENTAL INVESTIGATION OF PLANAR MICROSTRIP RESONATOR FOR PERMITTIVITY MEASUREMENT

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ABSTRACT
Characterization of dielectric material can be done by the nondestructive method of microstrip straight resonator and microstrip ring resonator sensor. To determine dielectric constant and loss tangent of solid, liquid and paste proposed measurement method is based on transmission line modeling (TLM) method in Time Domain. Dielectric constant is very much sensitive to variations in dimensions of microstrip planar structure. Straight and Ring resonators are fabricated with Glass Epoxy and RT Duroid substrate. Experimental work is carried out by measuring resonant frequency and return loss S_{21} on vector network analyzer (VNA). This study presents the determination of permittivity with variation in dimension of microstrip ring resonator and different low loss and high loss substrates. This study is helpful to specify correct dimensions of the sensor with the correct choice of substrate for accurate determination complex permittivity.

INDEX TERMS: Permittivity, Dielectric Constant , Loss Tangent , Microstrip Ring Resonator , Resonant Frequency

INTRODUCTION
There is an absolute need for measuring the dielectric properties of various food products and different materials [1]. In this paper simple and low cost system is investigated for correct measurement of relative permittivity ε_r [2][3]. For accurate sensor microstrip ring resonator and straight resonators with different substrate width and feed line length and gap width are fabricated and effective permittivity εeff is measured. The substrates used for the study include RT/Duroid 5880 and FR-4 of different thickness. The result of this study is presented with accuracy.
Printed wiring board materials (PWB) are necessary for design, analysis, and fabrication of antennas and microwave circuits [4][5]. The primary objective of this paper is to discuss different resonators over the broad frequency range. Microstrip resonator has different types of straight or liner resonator, the ring resonator, inverted and suspended resonators. Out of these microstrip ring resonator does not suffer from open-ended effects and can be used to give the more accurate measurement [6]. Because ring resonator has a higher quality factor and lower insertion loss than the straight or λ/2 resonator, therefore ring has the smaller 3dB bandwidth and sharper resonance then linear resonator. This makes the ring more desirable than for microstrip measurement. Microstrip ring resonator is the non-destructive and inexpensive technique to find dielectric properties of the wide range of materials. The electric field of ring resonator is perpendicular to the substrate sheet. Thus it provides information of printed wiring boards (PWB) low loss material like RT-Duroid 5880 and high loss material like FR-4. To obtain accurate S-parameters of the planar resonator, simulation is done using CST MWS in the time domain and frequency domain.

THEORY AND MODELLING
The dimension of ring resonator is calculated using well known expression given in K. Chang book [6] and Pozar's book[7].In order to calculate the radius of the ring, guided wavelength is computed using the equation (1)

$$\lambda g = \frac{C}{f\sqrt{\varepsilon eff}} \qquad (1)$$

Where λg, is guided wavelength, C is the speed of light, f is desired frequency and ε_{eff} is the effective dielectric constant. For measurement of complex Permittivity follwoing equations are used in frequency domain analysis .

The Maxwell equation for the time harmonic variation inside an isotropic material can be written as [9] per equation (2):

$$\nabla \times H = (\sigma + j\,\omega\varepsilon)E \qquad (2)$$

In this equation, H is the magnetic field, E is the electric field, ε is the complex permittivity, σ is the electric conductivity of the material, and ω is the angular frequency. The complex permittivity can be written as per equation (3):

$$\varepsilon_r = \varepsilon'_r - j\,\varepsilon''_r . \qquad (3)$$

The real part of the permittivity, also called the dielectric constant, affects the electric field and wave impedance of a propagating wave, whereas the imaginary part of the permittivity indicates how lossy a medium is. The loss tangent of the dielectric material is given by equation (4):

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} + \frac{\sigma}{\omega\varepsilon'} \qquad (4)$$

At microwave frequencies, the electrical conductivity of the dielectric material is extremely minimal, and the losses due to the friction in the polarization processes disappear at ω = 0 and increase with frequency are dominant [10]. Thus, the equation for the loss tangent is typically written as equation (5):

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \qquad (5)$$

The time required for electronic and atomic polarization and depolarization is very short less than 10-12 sec. The time required for orientation, space charge, or hopping polarization and depolarization is noticeably longer and varies in a wide range depending on the dielectric material. The polarization phenomena that require a longer time period than the electronic and atomic polarization are sometimes referred to as relaxation processes [10].

For time domain analysis [11] relation between return loss S21 , time delay Δt, effective permittivity ε_{eff} are given by following equations (6) and equation (7).

$$\Delta t = \frac{2\,\pi R}{C}\sqrt{\varepsilon_{eff}} \qquad (6)$$

Where R is mean radius of ring resonator , C is speed of light.

$$S_{21} = \sum_{n=0}^{\infty} e^{-2\pi nR\gamma_{eff}} \qquad (7)$$

DESIGN OF RESONATOR

Complex Permittivity can be measured with the help of straight resonator as well as ring resonator [9]. But return loss is more in straight resonator, so ring resonator is selected for complex permittivity measurement. To optimize the structure various substrates with different dielectric constant and thickness are used. Table 1 shows different dimensions of ring resonators with various substrates and different thickness.

Table 1 : Various substrates used for development of resonator sensor

Substrate	Dielectric Constant	Loss Tangent	Thickness (mm)	Mean Radius (mm)	Width (mm)
Alumina	9.8	0.0001	0.508	7.585	0.49
RT Duroid 5880	2.2	0.0009	1.575	14.2	4.8
RT Duroid 5880	2.2	0.0009	0.762	14.2	2.36
FR4 Epoxy	4.4	0.025	1.6	10.69	3
GML 1000	3.2	0.0004	0.762	12.2	1.84

Straight and ring resonators are simulated in CST MWS (Computer Simulation Technology Microwave Studio). Coupling Gap plays in important role in maximum power transfer. To measure the resonant frequency, a resonator is fed by microstrip line through gap coupling. To obtain maximum power transfer between resonator and feed line, the resonator must be matched to the feed at the resonant frequency. The resonator is then said to be critically coupled to the feed. Many simulation results are compared with gap varied from 0.1mm to 0.5mm. 0.3mm gap is the critically coupled gap giving highest quality factor Q. Table 2 shows variation in Q due to different coupling gaps and both resonators made with RT duroid 5880 substrate with 1.575 mm thickness.

Table 2: Effect of varying coupling gap on Q for ring and straight resonators

Coupling gap(mm)	Ring resonator (Q)	Straight resonator (Q)
0.1	56	51.3
0.2	67	61.99
0.3	76	70
0.4	66.21	61.12
0.5	20	43.2

Availability of substrates in the lab is glass epoxy FR4 and RT Duroid 5880. The simulation result shows that losses with RT Duroid ring resonator are lesser that FR4 substrate ring resonator. Maximum Q & minimum loss S_{21} is achieved with ring resonator rather than the straight resonator.

MEASURING SET UP

The measuring setup is as shown in Fig. 1. of the straight resonator and ring resonator for 2.45 GHz with RT-Duroid 5880. To determine material permittivity, it is necessary to measure resonating frequency fr, bandwidth BW, return loss S21. S-parameter measurement was performed by vector network analyzer(VNA) 8714ET as shown in Fig. 2 and Fig.3. The analysis is done for fr and Q with the help of VNA. Then effective permittivity is predicted. Experimental results are then verified with simulated results. Dielectric constant and tan delta is calculated as per equation (9) and equation (10) with reference to [12] [13].

$$\epsilon_{eff\,2} = \frac{fr_1^2}{fr_2^2}\ \epsilon_{eff\,1} \qquad (9)$$

$$Q_u = \frac{Q_L}{1 - S_{21}} \qquad (10)$$

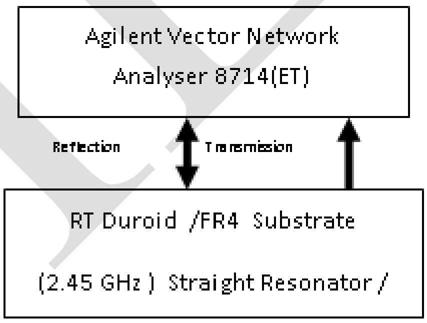

Figure 1: Experimental Set up

Where unloaded quality factor Q_u is determined by experimental loaded Q factor Q_L. Effective permittivity ε_{eff} is inversely proportional to resonating frequency fr. Ratio of effective permittivity and resonating frequency helps to determine relative permittivity.

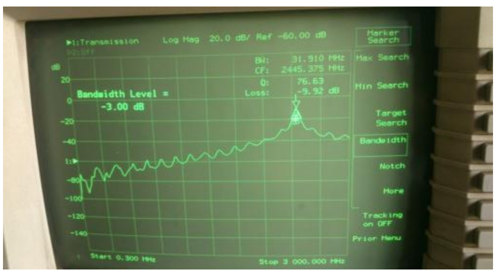

Figure 2: Permittivity Measurement Set Up Figure 3: VNA (8714 ET) Reading

RESULTS

Permittivity is measured by frequency domain and time domain analysis for RT Duroid and FR4 substrate. Table 3 shows simulated results on CST MWS in Time Domain. Time delay and effective permittivity relationship is calculated as per above equation (6). Table 4 shows simulated results on CST MWS in Frequency Domain and effective permittivity is calculated as per equation (9).

Table 3 : Permittivity measured from Time Domain Result

Substrate (MUT)	Time Delay (pSec)	Effective Permittivity	Relative Permittivity	Radius (mm)
FR-4	399.4	3.3	4.4	10.5
RT Duroid	406.7	1.87	2.2	14.2

Table 4 : Permittivity measured from Frequency Domain Result

Substrate (MUT)	Resonating Frequency (GHz)	S_{21} (dB)	Effective Permittivity	Relative Permittivity
FR-4	2.397	-10.51	3.3	4.3
RT Duroid	2.445	-9.92	1.87	2.19

CONCLUSION

The result of experimentation provides useful information about characterizing of different low loss RT-Duroid and high loss glass epoxy printed wiring board substrate material. Permittivity is calculated using time domain as well as frequency domain. Optimized planar ring resonator made up with RT Duroid substrate can be used for solids and semi solids material characterization. Liquids and viscous fluid type foods permittivity can also be measured. Simulation results and experimental results of permittivity measurement are in good agreement.

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REFERENCES

1) M.S.Venkatesh ,S.S.V.Raghavan ,*“An Overview of Dielectric Properties Measuring Techniques”, Canadian Biosystems Engineering Volume 47, 2005*

2) D.Thompson, M. Falah, X. Fang and D. Linton, “*Dielectric Characterization Using the Microstrip Resonator Method” , IEEE transactions Electron Devices 2003 , pp 23-26*

3) A. Kunte and S. Kulkarni, *“Experimental investigation of complex permittivity and detemination of ethanol content in gasoline,” in Proc IEEE International Microwave Conference, pp. 171–174, 2008.*

4) Janne-MattiHeinola,KimmoTolsa *, “Dielectric Characterization of Printed Wiring Board Materials Using Ring Resonator Techniques:A Comparison of Calculation Models”, IEEE Transactions on Dielectrics and Electrical Insulation Vol. 13, No. 4; August 2006, pp717-726*

5) Atabak Rashidian, Mohammadreza T Aligodarx and D. M. Klymyshyn , *“Dielectric characterisation of materials using a modified microstrip ring resonator technique”, IEEE Transactions on Dielectrics and Electrical InsulationVol. 19, No. 4; August 2012, pp1392-1399*

6) K.Chang and L.H.Hesieh, *“Microwave Ring Circuits and Related Structures”, John Wiley & Sons Inc. publication, second ed., 2004*

7) M. T.C.Edwards, *Foundations of Interconnect and Microstrip Circuit Design. John Wily and Sons,Ltd, 3rd ed., 2000.*

8) David M Pozar*, " Microwave Engineering ", 4th Edition ,John Wiley & Sons Publications*

9) A.A.Kunte,A.N.Gaikwad, S.G.Kulkarni, "Investigation of Transmission Line Modelling Method for Dielectric Characterization using Ring Resonator", IEEE International Applied Electromagnetic Conference, AEMC 2015,pp1-2, Dec 2015

10) C. K. Kao, "*Dielecric Phenomena in Solids ", Elsevier Academic Press , California 2004, pp 86-99.*

11) Yuto Kato, Masahiro Horibe, Michitaka Ameya, And Satoru Kurokawa ,"*Study on measurement method of permittivity for low-loss materials using microstrip ring-resonator", Proceedings of Asia-Pacific Microwave Conference 2014*

12) K.Joshi, R.D.Pollard, "*Microstrip resonator technique for non-destructive complex permittivity / moisture measurement", Proc. IEEE MTT International Microwave Symposium, Vol4, issue1999 June1999 page(s): 1863-1866*

13) Darko Kajfez , *" Q factor measurements with network analyzer", IEEE Transactions on Microwave Theory and Techniques ,Volume 32, Issue 7, Jul 1984.*