APPLICATION OF A DIELECTRIC RESONATOR ON MICROSTRIP LINE FOR A MEASUREMENT OF COMPLEX PERMITTIVITY

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Abstract

A cylindrical dielectric resonator placed on microstrip line is used for measuring the complex permittivity of microwave low-loss high ε_r dielectric materials. The method is based on the accurate solution of this resonator with $TE_{01\Delta}$ mode and is compared to the method of dielectric rod resonator with TE_{011} mode. The accuracy of the both method is similar - the measurement accuracy of relative dielectric constant is better than 0.2 percent and measurement accuracy of loss tangent is about $1\cdot10^{-4}$.

Introduction

In microwave measurements of low-loss high-permittivity ε_r /$\varepsilon_r \geqslant 10$/ dielectric materials there are very useful methods utilizing dielectric resonators. Up to day the dielectric rod resonator /Fig.1./ with TE_{011} mode is in general used [1] - [3] because the accurate solution of this structure is well known. On the base of rod resonator structure there have been built dielectrometers.

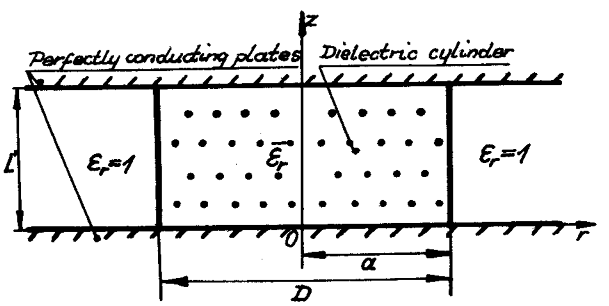

Fig.1. A cylindrical dielectric rod resonator

This paper describes application of dielectric resonator placed on microstrip line for a measurement of complex permittivity. This method is competitive to rod resonator one. Recently, dielectric resonator in MIC configuration has been considered in literature [4] - [11] because of increasing applications of this structure in microwave integrated circuits as in temperature-compensated oscillators, low-noise synthesizers and in high-Q filters. The analysis for a such resonator has been performed by using several approximate methods /such as a magnetic wall model, a variational model, a dielectric waveguide model and mixed model/ but only for some specific structures accurate solutions are given [7], [9], [11]. In most considered cases the all dielectric materials was assumed to be lossless. Presented method for determination of the relative dielectric constant and loss tangent $\tan\delta$ of the dielectric is based on the knowledge of accurate solution of Maxwell's equations in dielectric resonator coupled to microstrip line /Fig.2./ with $TE_{01\Delta}$ mode.

Solution of dielectric resonator

The structure under investigation is shown in Fig.2.

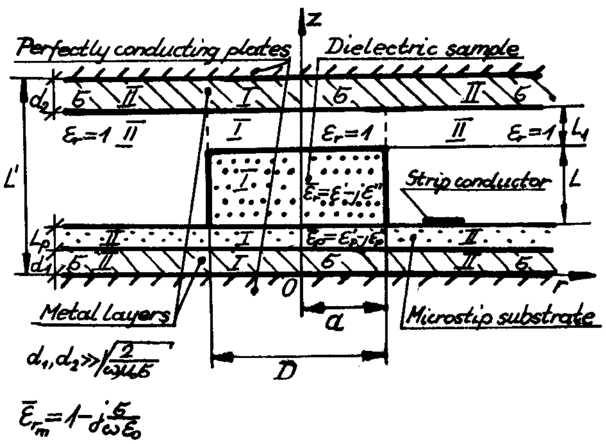

Fig.2. A dielectric resonator in MIC

The fundamental steps of the solution are: 1/ dividing the space between the perfectly conducting plates into two regions:

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I for $r<a$ and II for $r>a$ /where a is the radius of the dielectric sample/; 2/ solving Maxwell's equations within each region; 3/ matching the resulting fields on the surface r=a. The two regions are multilayer radial waveguides and may have any finite number of layers. The electromagnetic fields of TE_{onm} modes with a complex angular frequency

$$\varpi = \omega' + j\omega'' = \omega_o\left(1 + j\frac{1}{2Q_o}\right) \qquad /1/$$

can be expressed as linear combination of TE_{om} /m=1,2,.../ modes in each multilayer radial waveguide:
in region I

$$H_z^I(r,z) = \sum_{i=1}^{\infty} b_i\, J_o\left(h_i^I a\right) G_i^I(z) \qquad /2a/$$

in region II

$$H_z^{II}(r,z) = \sum_{j=1}^{\infty} c_j\, K_o\left(y_j^{II} a\right) G_j^{II}(z) \qquad /2b/$$

where K_k and J_k are adequate modified Hankel functions of k-th order and Bessel functions of the first kind of k-th order. The functions $G_i^I(z)$ and $G_j^{II}(z)$ describe dependences of H_z on coordinate z for TE_{oi} modes and TE_{oj} modes in two regions, respectively and satisfy the equations

$$\frac{d^2 G_i^{\alpha}(z)}{dz^2} + \left(\omega^2 \mu_o \varepsilon_o \varepsilon_r^{\alpha} - t_i^{\alpha}\right) G_i^{\alpha}(z) = 0 \qquad /3/$$

/i=1,2,3,...; α = I,II/

for $0 \leqslant z \leqslant L'$ with boundary conditions $G_i^I(0) = G_i^I(L') = G_j^{II}(0) = G_j^{II}(L') = 0$.
Coefficients $t_i^I = \left(h_i^I\right)^2$ and $t_j^I = \left(y_j^I\right)^2$ are the eigenvalues of G_i^I and G_j^{II} respectively.
The complex angular frequency ϖ and coefficients b_i, c_j at the respective field modes are selected such to satisfy continuity conditions at cylinder wall of radius r = a,

$$H_z^I(a,z) = H_z^{II}(a,z) \qquad /4a/$$

$$E_\varphi^I(a,z) = E_\varphi^{II}(a,z) \qquad /4b/$$

and ϖ is determinated from condition:

$$\det\,[W] = 0 \qquad /5/$$

where the elements of the matrix [W], with infinite number of columns and lines, is given by expression:

$$w_{ij} = \int_0^{L'} G_i^I(z)\, G_j^{II}(z)\, dz \left[\frac{K_1\left(y_j^{II} a\right)}{J_1\left(h_i^I a\right)} + \frac{y_j^{II}\, K_o\left(y_j^{II} a\right)}{h_i^I\, J_o\left(h_i^I a\right)}\right]$$

$$i = 1,2,3,\ldots \qquad /6/$$

For the practical purpose there is enough to take into account 5 ÷ 10 waveguide modes.

Presented method allows to find full chart of modes /TE_{om1}, TM_{om1}, HE_{nm1}, EH_{nm1}, TM_{nmo}/ in structure shown in Fig.2. For this purpose electromagnetic fields of these modes ought to be represented by linear combination of all $TE_{n\,p+1}$ and TM_{np} modes /n,p = 0,1,2,../ of multilayer radial waveguide in region I and II, separately.

Measurement results and analysis of accuracy

Utilizing reaction coupling of cylindrical dielectric sample to microstrip line /through the magnetic field/ there have been measured resonator parameters. For the optimum measurement accuracy the dielectric sample should be placed in such a distance from the strip conductor /Fig3/ that value of coupling coefficient is 0.5 ÷ 1.5. The measurements have been made in frequency band 1 ÷ 12 GHz using Network Analyzer 8410A. Theoretical and experimental results received by the presented method have been compared to the results by rod resonator method. Example of a few results is given in table 1.

For estimation of a measurement accuracy there has been made numerical analysis of equation /5/ which gives, e.g. for resonator No 1, the following expressions for the maximum relative errors:

$$\left|\frac{\Delta\varepsilon_r}{\varepsilon_r}\right| = 2.03\left|\frac{\Delta f_o}{f_o}\right| + 0.98\left|\frac{\Delta D}{D}\right| + 0.91\left|\frac{\Delta L}{L}\right| + 0.21\left|\frac{\Delta L_1}{L_1}\right| + 0.08\left|\frac{\Delta L_p}{L_p}\right| \qquad /7/$$

$$\left|\frac{\Delta \tan\delta}{\tan\delta}\right| = 1.41\left|\frac{\Delta Q_o}{Q_o}\right| + 0.2\left|\frac{\Delta\sigma}{\sigma}\right| + 0.34\left|\frac{\Delta f_o}{f_o}\right| + 0.27\left|\frac{\Delta D}{D}\right| + 0.49\left|\frac{\Delta L}{L}\right| + 0.11\left|\frac{\Delta L_1}{L_1}\right| \qquad /8/$$

The influence of realitive measurement errors of other parameters, e.g. microstrip substrate parameters, for accuracy measurement of dielectric sample complex permittivity is negligible. Some coefficients in equation /7/ /i.e. near relative error of resonant frequency measurement, and total near relative errors of dimensions measurement/ are the same as in rod resonator method [2] . Measurement accuracy of relative dielectric constant in the both methods is mainly limited by measurement accuracy of resonator dimensions and resonant frequency. But measurement accuracy of loss tangent is mainly limited by measurement accuracy of Q and knowledge of metal layer condutivity. In whole frequency band the measurement accuracy of relative dielectric constant is better than 0.2 percent, but measurement accuracy of loss tangent is better than $1 \cdot 10^{-4}$.

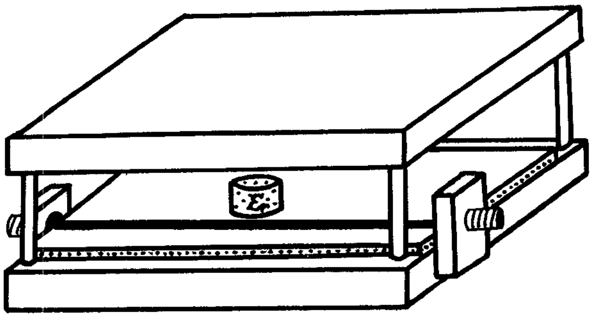

Fig.3. Microstrip dielectrometer

Table 1. Example of measurement results in rod resonator method and in microstrip coupled resonator method.

Resonator No			1	2	3	4
Dimensions	L	mm	7.48	6.95	5.98	4.21
	D	mm	14.98	13.99	11.99	6.03
Rod resonator	f_o	MHz	4775	5131	5993	9701
	Q_o	-	1930	1690	1730	1440
	$\sigma \times 10^{-7}$	S/m	1.25	1.25	1.25	1.25
	ε'_r	-	34.17	34.14	33.89	36.00
	$\tan\delta \times 10^4$	-	1.96	2.57	2.21	3.80
Resonator in MIC	L_1	mm	0.72	1.25	2.215	10.10
	f_o	MHz	4348	4523	5050	8220
	Q_o	-	2470	2440	2410	1980
	$\sigma \times 10^{-7}$	S/m	6.14	6.14	6.14	6.14
	ε'_r	-	34.19	34.21	34.02	36.13
	$\tan\delta \times 10^4$	-	3.02	3.19	3.47	4.22
	Parameters of microstrip substrate: L_p=0.7 mm, ε'_p=9.6, $\tan\delta_p = 6 \cdot 10^{-4}$					

Conclusion

Utilizing accurate method of resonant frequency calculation for the multilayer dielectric resonator the new measurement method of complex permittivity of microwave insulators has been presented. Advantage of this measurement technique is that the mechanical construction of the proposed microstrip dielectrometer is simpler then in rod resonator method and that $TE_{01\Delta}$ mode in MIC configuration is the first resonant mode in trapped states /but TE_{011} mode in rod resonator is not the first/. Leaky state TM_{nmo} modes have a very low Q value and they are not remarked.

References

1. W.E.Courtney,"Analysis and evaluation of method of measuring the complex permittivity and permeability of microwave insulators" IEEE Trans.MTT-18, Aug. 1970.
2. M.W.Pospieszalski,"On the theory and application of the dielectric post resonator" IEEE Trans.MTT-25, Mar.1977.
3. Y.Kobayashi,S.Tanaka,"Resonant Modes of a Dielectric Rod Resonator Short-circuited at both end by parallel conducting" IEEE Trans.MTT-28,No.10, October 1980.
4. Y.Konishi,N.Hoshino,and Y.Utsumi "Resonant frequency of a $TE_{01\Delta}$ dielectric resonator" IEEE Trans.MTT-24,Feb. 1976.
5. T.Itoh and R.Rudokas "New method for computing the resonant frequencies of dielectric resonators" IEEE Trans. MTT-25, Jan.1977.
6. P.Guillon,Y.Garault,"Accurate resonant frequencies of dielectric resonators" IEEE Trans.MTT-25,Jan.1977.
7. M.Jaworski and M.W.Pospieszalski,"An accurate solution of the cylindrical dielectric resonator problem" IEEE Trans.MTT-27, July 1979.
8. T.Higashi,T.Makino,"Resonant frequency stability of the dielectric resonator on a dielectric substrate" IEEE Trans.MTT-29, October 1981.
9. M.Tsuji,H.Shigesawa,K.Takiyama,"On the complex resonant frequency of open dielectric resonators" IEEE Trans. MTT-31, May 1983.
10. Y.Shimoda,H.Tomimuro,K.Onuki,"A proposal of a new dielectric resonator construction for MIC's" IEEE Trans. MTT-31, July 1983.
11. K.A.Zaki,A.E.Atia,"Resonant frequencies of dielectric loaded waveguide cavities" 1983 IEEE MTT-S Digest Symposium, Boston May 1983.