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LOW-COST METHOD OF THE MEASUREMENT OF MICROWAVE FERRITE PARAMETERS

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Abstract

Theory and experimental results are presented to show the possibility of using a ferrite cylindrical specimen coupled to the microstrip line for measuring properties of magnetic materials at microwave frequencies. The complex permittivity and initial scalar permeability of ferrite are calculated on the base of the measured resonant frequencies and Q-factors of the structure with $TE_{01\delta}$-mode. The measurements are made, without saturation of tested material, for two (or more) different distances between ferrite sample and upper mobile metal plate of the holder. The measurement accuracies of real parts of permittivity and permeability are better than 0.2 percent, and measurement error of total loss tangent is less than 2 percent.

Introduction

Recent developments in the production of low-loss microwave magnetic materials as well as their wide-spread applications in microwave circuits have prompted a need for new precise and simple techniques of the measurements of their properties. Basic ferrite parameters and measurement methods have been described in numerous papers. Up to now, the cavity perturbation techniques have been the most popular ones [1]. Recently, in microwave measurements of high-permittivity dielectric materials there are very useful methods utilizing dielectric resonators in rod [2 , 3] and microstrip [4] configurations. Similar methods can be also applied for measuring the parameters of microwave ferrites. Paper [5] proposes to use TM_{011} mode in the dielectric rod resonator (i.e. cylindrical sample placed between two infinite parallel conducting plates), but paper [6] indicates advantages of the TE_{011} mode of this structure. Paper [7] describes the measurements of some ferrite parameters for ferrite cylindrical sample coupled to the microstrip line and placed between electromagnet pole pieces.

The methods presented in [6] and [7] are based on the assumption that magnetic and electric properties of the ferrite can be separated because the ferrite specimen in very large DC magnetic field (which saturates the ferrite and reduces the magnetic losses close to zero) is equivalent to the dielectric resonator. Therefore, in the such magnetized state, the complex permittivity is calculated on the base of measured resonant frequency and Q-factor. In the second state, for demagnetized sample the new resonant frequency and Q-factor are measured and, since value of the permittivity is constant (and known from the first measurement), the initial scalar permeability can be calculated. The basic disadvantage of the above methods is the necessity to saturate ferrite sample and therefore the need to use proper big and heavy electromagnets. Imperfect saturation is also a source of additional measurement errors.

This paper presents theory and experimental results of the measurements of complex permittivity and initial scalar permeability of microwave ferrites without any magnetization of the tested material. In the holder (Fig.1) with movable upper conducting plate there is mounted microstip line, on which ferrite cylindrical specimen is located. Material parameters are determined on the base of measured resonant frequencies and Q-factors of this structure with $TE_{01\delta}$-mode for two (or more) different distances between ferrite sample and movable plate.

Theoretical solution

The structure shown in Fig.1 can be treated as a specific case of a multilayered cylindrical ferrite (dielectric) resonator and possesses a rotational symmetry. Thus, the electric field of the most convenient for measurement applications mode-$TE_{01\delta}$ (usually, it is the fundamental mode) has only the φ-component and should satisfy the following wave equation:

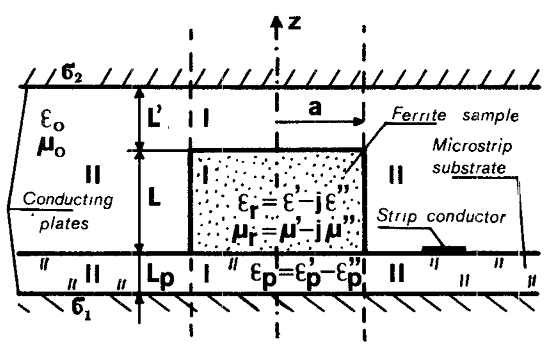

Fig.1. Ferrite resonator in microstrip configuration

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$$\frac{\partial^2 E_\varphi}{\partial z^2} + \frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial(rE_\varphi)}{\partial r}\right) + k_0^2\, \varepsilon_r\, \mu_r\, E_\varphi = 0 \qquad (1)$$

where: $k_0 = \omega\sqrt{\mu_0 \varepsilon_0} = 2\pi/\lambda_0$.

For the analysis purpose the discussed configuration is divided into two regions I and II, which are multilayered radial waveguide. The electromagnetic fields of TE_{omn} modes with a complex angular frequency

$$\tilde{\omega} = \omega' + j\,\omega'' = \omega_0(1 + j\,1/2\,Q_0) \qquad (2)$$

can be expressed as linear combination of TE^{α}_{omn} ($m=1,2,3,\dots,N$; α =I,II) modes in each multilayered radial waveguide. The coefficients of these combinations are selected such to satisfy boundary conditions at cylindrical wall of radius r = a. As a result there is obtained a set of equations with unknown coefficients. The solution of this set leads to a condition, in which the determinant of a matrix W is equal zero. The matrix W has 2N x 2N columns and lines, and matrix elements are only functions of complex angular frequency (2). Complex frequency can be calculated with any accuracy by increasing (in solution) the number of waveguide modes N. For the practical purpose it is enough to take into account 5 ÷ 10 modes and then the relative accuracy of resonant frequency and Q-factor determination is better than 10^{-7}.

In the calculations there is taken into account the influence of all holder parameters,i.e. microstrip substrate parameters and surface resistivities of the metallic plates.

Measurements

For the optimum measurement accuracy the tested ferrite samples should be placed in such a distance from the strip conductor that the value of the coupling coefficient (reaction-type coupling to the microstrip line through the magnetic field) is between 0.5 and 1.5. On the base of the two measured resonant frequencies and Q-factors for two different distances between ferrite specimen and movable upper plate (additional low permittivity support between microstrip substrate and tested sample can be also used) it is possible to calculate two unknown parameters: complex ferrite permittivity and complex initial permeability.

Many ferrite materials manufactured by different companies (Thomson, Trans-Tech, Polfer) have been measured and the results have been compared with catalog parameters as well as with results obtained by means of Courtney method [6]. The examples of a few results are given in Table 1. The measurement accuracies of relative dielectric (ε') and initial magnetic (μ') constants are better than 0.2%, but measurement error of total loss tangent is less than 2%. In the table there is given only tangent of total loss because tangents of electric and magnetic loss can be determinated with poor accuracy which is limited by measurement accuracy of Q-factor.

Conclusion

The radial mode matching method has been successfully applied for accurate analysis of ferrite cylindrical resonator coupled to microstop line. On the base of theoretical solution and developed computer program there has been proposed a new low-cost and accurate method for the measurement of some ferrite parameters. The complex permittivity and initial permeability can be measured without need to magnetize tested material. It is also possible to calculate the value of saturation magnetization of the ferrite material. The measurements have been made in microstrip holder, however, the theoretical solution of the multilayered ferrite resonator is universal and it can be utilized for other holder configurations,e.g. cylindrical cavity, modified Courtney holder.

References

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Table 1. Examples of measurement results (parameters of microstip substrate L_p=0.762 mm, ε_p=2.45, $\tan\delta_p$=2 10^{-3})

Resonator No		1	2	3
This method	D mm	8.39	14	7.75
	L mm	8.39	4	4.9
	L'_1 mm	0.52	2.7	0.85
	L'_2 mm	1.50	3.4	1.9
	f_1 GHz	9.153	8.172	10.866
	f_2 GHz	8.937	8.044	10.499
	Q_1	1876	580	576
	Q_2	1926	587	587
	ε	14.04	15.09	14.91
	μ	0.995	0.981	0.9985
	$\tan\delta \times 10^4$	5.1	16.5	16.8
Courtney method	ε	14.14	15.1	14.5
	μ	0.998	0.998	0.999
	$\tan\delta \times 10^4$	5.9	17	15