54. IWK

Internationales Wissenschaftliches Kolloquium
International Scientific Colloquium

Information Technology and Electrical Engineering - Devices and Systems, Materials and Technologies for the Future

Faculty of Electrical Engineering and Information Technology

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TECHNISCHE UNIVERSITÄT
ILMENAU

Impressum

Herausgeber: Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Dr. h. c. Prof. h. c.
Peter Scharff

Redaktion: Referat Marketing
Andrea Schneider

Fakultät für Elektrotechnik und Informationstechnik
Univ.-Prof. Dr.-Ing. Frank Berger

Redaktionsschluss: 17. August 2009

Technische Realisierung (USB-Flash-Ausgabe):
Institut für Medientechnik an der TU Ilmenau
Dipl.-Ing. Christian Weigel
Dipl.-Ing. Helge Drumm

Technische Realisierung (Online-Ausgabe):
Universitätsbibliothek Ilmenau
ilmedia
Postfach 10 05 65
98684 Ilmenau

Verlag: isle
Verlag ISLE, Betriebsstätte des ISLE e.V.
Werner-von-Siemens-Str. 16
98693 Ilmenau

ISBN (USB-Flash-Ausgabe): 978-3-938843-45-1
ISBN (Druckausgabe der Kurzfassungen): 978-3-938843-44-4

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=14089

DETERMINATION OF COMPLEX PERMITTIVITY AND PERMEABILITY OF FERRIMAGNETIC NANOPOWDERS AT MICROWAVES

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ABSTRACT

A technique of determination of complex permittivity and permeability of ferrimagnetic nanopowders using S-parameter measurements in rectangular waveguide and results of its study are presented in this paper. The permittivity and permeability of the ferrimagnetic nanopowders are determined by the novel technique in which magnitudes of S-parameters are used only. Use of the technique allows to simplify experimental measurements for determination of complex permittivity and permeability of the materials and to replace expensive vector network analyzers (VNA) with simple scalar network analyzers (SNA).

Index Terms **-** complex permittivity and permeability, ferrimagnetic nanopowders, S-parameters.

1. MAIN PART

Ferrimagnetic materials are one of kinds of materials effectively absorbing and shielding electromagnetic radiation [1]. Barium hexaferrite (BHF) nanopowders occupy a special place among ferrimagnets due to a possibility of control of their magnetic properties over a wide range and their frequency properties at a fabrication stage in a wide frequency band from 1 GHz up to 40 GHz by partial substitution of trivalent iron ions by pairs of other metals ions, one of which is bivalent another tetravalent [2, 3]. Design of coating with the specified parameters of microwave shielding and absorption requires knowledge of complex permittivity and permeability of the initial material – doped barium hexaferrite.

Waveguide methods are used for determination of complex permittivity and permeability now. The methods require using of measured complex values of reflection coefficient and forward transmission coefficient of a waveguide structure filled with tested material. Expensive vector network analyzers are applied for the measurements [4].

A novel technique is presented in which complex permittivity and permeability of the BHF powder is determined by results of measurements in the waveguide only magnitudes of S-parameters. A use of this method allows to simplify experimental measurements for determination of permittivity and permeability of materials and to replace expensive vector network analyzers with simple scalar network analyzers.

A sensor similar to one described in [5] as a rectangular waveguide section containing a three-layer structure is used by the method. The waveguide sensor design is shown in Fig. 1. The rectangular waveguide section between two dielectric plates which are located perpendicularly to waveguide walls is filled by the tested material – BHF powder.

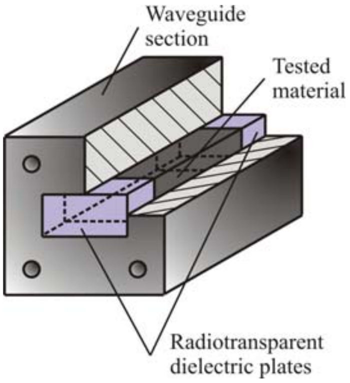

Figure 1 The waveguide sensor design

Determination of complex permittivity and permeability is an inverse electrodynamic problem [5]. The solution of the inverse problem is extraction of the complex permittivity $\dot{\varepsilon}$ and permeability $\dot{\mu}$ from its indirect displays – measured magnitudes of the reflection coefficient $\left|\dot{S}_{11M}\right|$ and the forward transmission coefficient $\left|\dot{S}_{21M}\right|$ of the sensor containing the tested material.

The inverse problem has been formulated in form of problem of search of a minimum of goal function presented unlike [6] by the expression

$$U(\dot{\varepsilon},\dot{\mu}) = \sum_{i=1}^{N} \left(\left|\dot{S}_{11Ci}(\dot{\varepsilon},\dot{\mu})\right| - \left|\dot{S}_{11Mi}(\dot{\varepsilon},\dot{\mu})\right|\right)^2 + \\ + \left(\left|\dot{S}_{21Ci}(\dot{\varepsilon},\dot{\mu})\right| - \left|\dot{S}_{21Mi}(\dot{\varepsilon},\dot{\mu})\right|\right)^2, \qquad (1)$$

where $\left|\dot{S}_{11C}\right|$, $\left|\dot{S}_{21C}\right|$ – magnitudes of the scattering parameters of the sensor, which are calculated by use of the expressions obtained on the basis of an exact solution of a direct boundary electrodynamic problem of diffraction for the sensor. Summing in expression (1) is carried out by index $i=1,\ldots,N$, where N – number of frequency points on which scattering parameters have been measured.

The exact solution of the scattering problem of H_{10}-mode by the treelayer structure filled with the tested material is obtained by the technique of partial areas. The model of the waveguide sensor with threelayer structure is shown in Fig. 2.

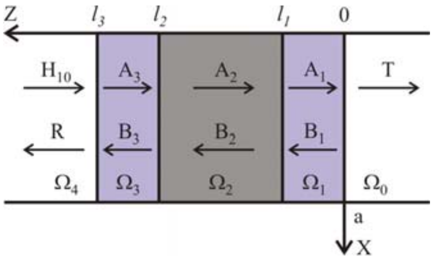

Figure 2 The model of the waveguide sensor

The elements of the scattering wave matrix are determined by the final expressions

$$\dot{S}_{11} = R = e^{-j\frac{\pi}{a}l_3\sqrt{\Delta^2-1}} \times$$

$$\times \frac{Q_1\left(1-\frac{\gamma_3}{\gamma_0\mu_3}\right)e^{-j\frac{\pi}{a}L_{32}\sqrt{\Delta^2\varepsilon_3\mu_3-1}} + Q_2\left(1+\frac{\gamma_3}{\gamma_0\mu_3}\right)e^{j\frac{\pi}{a}L_{32}\sqrt{\Delta^2\varepsilon_3\mu_3-1}}}{Q_1\left(1+\frac{\gamma_3}{\gamma_0\mu_3}\right)e^{-j\frac{\pi}{a}L_{32}\sqrt{\Delta^2\varepsilon_3\mu_3-1}} + Q_2\left(1-\frac{\gamma_3}{\gamma_0\mu_3}\right)e^{j\frac{\pi}{a}L_{32}\sqrt{\Delta^2\varepsilon_3\mu_3-1}}};$$

$$\dot{S}_{21} = T =$$

$$= \frac{16\cdot e^{-j\frac{\pi}{a}l_3\sqrt{\Delta^2-1}}}{Q_1\left(1+\frac{\gamma_3}{\gamma_0\mu_3}\right)e^{-j\frac{\pi}{a}L_{32}\sqrt{\Delta^2\varepsilon_3\mu_3-1}} + Q_2\left(1-\frac{\gamma_3}{\gamma_0\mu_3}\right)e^{j\frac{\pi}{a}L_{32}\sqrt{\Delta^2\varepsilon_3\mu_3-1}}},$$

where $L_{32}=l_3-l_2$, $\Delta=f/f_c$, f_c – the critical frequency of the waveguide for H_{10}-mode, Q_1, Q_2 – coefficients which are defined by the geometrical sizes and the parameters of the materials filling areas, $\gamma_i=\sqrt{k^2\varepsilon_i\mu_i-(\pi/a)^2}$ – the H_{10}-mode propagation constant; $k=2\pi/x$ – wavenumber; $j=\sqrt{-1}$.

Such approach has allowed to execute regularizing of an incorrect inverse problem of determination $\dot{\varepsilon}$ and $\dot{\mu}$ by scattering parameters for one frequency point and to obtain the goal function of the kind (1), that have only one minimum. Coordinates of minimum point of the goal function give an average values of the real and imaginary components of complex permittivity and permeability for this frequency band.

Obtained results have shown a stability of operation of the computing procedures and a possibility of determination of complex permittivity and permeability with a required error.

We would like to thank Dr. Bernd Halbedel for samples of materials kindly presented to our using and helpful discussions.

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