Measurement of complex permittivity and permeability of hexagonal ferrite composite material using a waveguide in microwave band

by Erfan Handoko
Measurement of Complex Permittivity and Permeability of Hexagonal Ferrite Composite Material Using a Waveguide in Microwave Band

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Abstract—This paper reports a method for measuring the complex permittivity and permeability of hexagonal ferrite composite as lossy material. The measurement using a waveguide in the microwave band. In order to measure the S-parameter of hexagonal ferrite, a sample should completely fill in the waveguide end and the sample holder. The complex permittivity and permeability of the hexagonal ferrite composite material are measured using the vector network analyzer (VNA) in the frequency range from 7 to 14 GHz. Their complex permeability and permittivity, magnetic and dielectric loss tangent values were calculated at given thickness according to NRW formula and transmit line method in microwave frequency. The proposed measurement method can be a useful technique for measuring dielectric and magnetic properties of absorbing materials.

Keywords—Hexagonal ferrite composite; complex permittivity and permeability; waveguide; NRW and transmit line method

I. INTRODUCTION

Due to the usefulness of microwave absorbing materials for telecommunication systems and military systems, research on radar absorbing material (RAM) attracts considerable attention in many countries [1,2]. The measurement of the complex permittivity and permeability in solid materials, the S-parameter method employing a waveguide line is applied [3]. Various methods for the measurement of the complex permittivity and permeability of the solid materials have been reported [4,5]. Few results of the measurement of their composition of hexagonal ferrite have been reported for determination of the complex permittivity and permeability in X-band frequencies [6-9].

In this paper, a hexagonal ferrite composite material with a thickness d is placed in a rectangular waveguide. With a vector network analyzer, we measure the reflection S11 and transmission factor S21 of the structure in the microwave band 7-14 GHz. Based on these measurements, the complex permittivity and permeability of hexagonal ferrite composite material are determined by Nicolson-Ross-Weir (NRW) method.

II. EXPERIMENTAL METHOD

Hexagonal ferrite, BaFe$_2$O$_4$Ti$_x$Mn$_{1-x}$O$_3$ was synthesized from stoichiometric mixtures of BaCO$_3$, Fe$_2$O$_3$, Co$_2$O$_3$, Ti$_2$O$_3$, and MnCO$_3$ by ceramic method and crushed for 1 h and sintered at 1100 °C for 5 h. The composite material was prepared by mixing ferrite with epoxy resin. The sample was characterized at room temperature using vector network analyzer (VNA) Rohde-Schwarz ZVL13 to measure the reflected signal (S11) and transmitted signal (S21) for 7-14 GHz frequencies. S11 and S21 parameters from measurement are used to calculate the complex permittivity, permeability and tangent loss.

III. RESULTS AND DISCUSSION

A. Sample Preparation and Transmission Line Method

Fig. 1 shows transmission line methods involve placing hexagonal ferrite material inside a portion of an enclosed transmission line. The transmission line used here is a section of rectangular waveguide for X-Band Applications. The complex relative permittivity ($\varepsilon_r$) and permeability ($\mu_r$) are then calculated for given thickness according to Nicolson-Ross-Weir (NRW) method [10] from the measurement of the reflected signal (S11) and transmitted signal (S21).

Hexagonal ferrite composite with sample holder (Fig. 1) is placed in a waveguide with width 22.86 mm, height 10.16 mm and thickness 2 mm. The complex valued S-parameters are obtained by a vector network analyzer measurement (Fig. 2). The NRW method is then formulated using the following steps.
By defining the function (4) and (6), the complete reflection and transmission coefficient can be determined and hence derived from the complex equation

\[
\left[ \begin{array}{c} \frac{P}{P_0} \\ \frac{T}{T_0} \end{array} \right] = \frac{1}{r} \left[ \begin{array}{c} 1 - r \cos \theta \pm i \sin \theta \\ 1 + r \cos \theta \pm i \sin \theta \end{array} \right]
\]

where \( \theta \) and \( \tan \) are the phase space and the complex wavevector

\[
\left( \frac{P}{P_0} \right) = \frac{1}{r} \left( 1 - \frac{r}{1 + r} \right)
\]

\[
\left( \frac{T}{T_0} \right) = \frac{1}{r} \left( 1 + \frac{r}{1 + r} \right)
\]

with the measured parameters the complete reflection and transmission coefficient can be determined by

1. The complex reflection and transmission proportion can be found by

\[
\frac{P}{P_0} = \frac{1}{r} \left( 1 - \frac{r}{1 + r} \right)
\]

and

\[
\frac{T}{T_0} = \frac{1}{r} \left( 1 + \frac{r}{1 + r} \right)
\]

Then the reflection coefficient \( R \) is given by

\[
R = \frac{P}{P_0}
\]

\[
T = \frac{T}{T_0}
\]

\[
K = \frac{P}{T}
\]

1. The complex reflection and transmission proportion can be found by

\[
\frac{P}{P_0} = \frac{1}{r} \left( 1 - \frac{r}{1 + r} \right)
\]

\[
\frac{T}{T_0} = \frac{1}{r} \left( 1 + \frac{r}{1 + r} \right)
\]

The measured and calculated data are also shown at the right.

---

The figure shows the reflection and transmission results of a material derived

\[
\frac{P}{P_0} = \frac{1}{r} \left( 1 - \frac{r}{1 + r} \right)
\]

\[
\frac{T}{T_0} = \frac{1}{r} \left( 1 + \frac{r}{1 + r} \right)
\]

and

\[
\frac{P}{T} = \frac{1}{r}
\]

The measured and calculated data are also shown at the right.

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The figure shows the reflection and transmission results of a material derived

\[
\frac{P}{P_0} = \frac{1}{r} \left( 1 - \frac{r}{1 + r} \right)
\]

\[
\frac{T}{T_0} = \frac{1}{r} \left( 1 + \frac{r}{1 + r} \right)
\]

and

\[
\frac{P}{T} = \frac{1}{r}
\]

The measured and calculated data are also shown at the right.
D. Loss Tangent

With eq. (7) and (8) we calculated loss tangent of the material. As we can see in Fig. 4, the losses are higher at the middle frequencies as about 11.5 GHz.

IV. CONCLUSION

The measurement of the electromagnetic parameters of hexagonal ferrite composite material have resulted good complex permittivity and permeability, which were calculated at given thickness according to Nicolson-Ross-Weir (NRW) method from the measurement of the reflected signal (S11) and transmitted signal (S21). From the results obtained that no anomalies were noticed because resonance in phase for the 1 mm in thickness sample occurs between 7 and 14 GHz. The results overcome a possible disadvantage of using the NRW method. From these results it is possible to conclude that the used procedure obtains a good experimental characterization of magnetic and dielectric of other materials.

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