Determination of the Complex Permittivity of E-glass and Balsa wood using a Rectangular Waveguide System

Shaikha AlDhaheri, Papa Ousmane Leye, Chaouki Kasmi, and Nicolas Mora
Directed Energy Research Center, Technology Innovation Institute, Abu Dhabi, United Arab Emirates
shaikha.aldhaheri@tii.ae

***Abstract*—** This paper investigates the electromagnetic properties of E-glass and balsa wood, two commercially available dielectric materials. The samples are characterized by calculation and measurement over the X and Ku band frequency ranges (8.2 -18 GHz). A rectangular waveguide system is used for the measurement. The Nicolson Ross Weir (NRW) algorithm is implemented to calculate the complex permittivity and magnetic permeability from the measured S_{11} and S_{21} parameters. In addition, this paper discusses some limitations of the NRW technique to characterize complex permittivity and permeability of low loss materials at frequencies corresponding to multiples of one-half wavelength in the material.

Keywords- electromagnetic characterization, electric permittivity, magnetic permeability, Nicolson Ross Weir (NRW) method, rectangular waveguide

I. INTRODUCTION

The electromagnetic characterization of dielectric materials is relevant to a wide range of practical applications [1]. The use of radar absorbing material (RAM) is a must to stealth the object by reducing the radar cross-section. Several experimental techniques and methods have been developed over the years to measure the complex relative permittivity and complex relative permeability of the materials [1]–[3]. In this paper, the NRW technique is implemented to extract the complex permittivity and permeability of E-glass and balsa wood samples in the X and Ku frequency bands. The equations used and the algorithm to convert from S parameters to dielectric properties are presented. The measurement setup, the calibration, and the measurement procedure are outlined. The measurement results are then compared with the calculation for validation. Finally, the divergence of the NRW technique at frequencies corresponding to multiples of one-half wavelength in the material is highlighted and discussed.

II. MEASUREMENT SETUP

To validate the technique, the samples are measured using a rectangular waveguide system: WR90 for operating frequencies from 8.2 to 12.4 GHz and WR62 from 12.4 to 18 GHz. The experimental setup is shown in Figure 1[2]. A VNA Rhode 'and' Schwartz ZNB20, operating from 100 kHz to 20 GHz, and WR90 and WR62 Standard CLKA1 waveguides from Rhode & Schwarz are used to performing the measurement. The material under test is placed between the waveguides, and the S-parameters are measured at the ends of the coaxial cables.

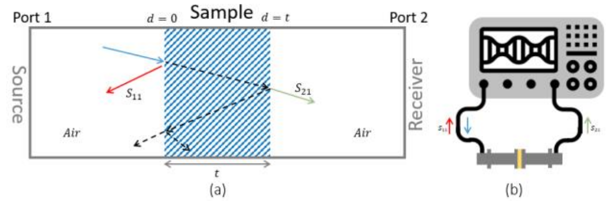

Figure 1: (a) Waveguide section filled with material sample, (b) Experimental setup.

III. METHOD AND DISCUSSION

By assuming no source and load mismatch and solving the boundary condition at d = 0 and d= t, S_{11} and S_{21} can be written as functions of the reflection coefficient (R) and the transmission (T) coefficient between the two faces of the sample [4]:

$$S_{11} = \frac{(1-T^2)R}{1-T^2R^2} \quad (1) \quad ; \quad S_{21} = \frac{(1-R^2)T}{1-T^2R^2} \quad (2)$$

The permittivity and permeability are extracted using the following relationships:

$$\mu_r = \left(\frac{1+\mathrm{R}}{1-\mathrm{R}}\right)\frac{\gamma}{j2\pi\sqrt{\frac{1}{\gamma_0^2}-\frac{1}{\gamma}}} \quad (3) \quad ; \quad \varepsilon_r = \frac{\lambda_0^2\left[\frac{1}{\lambda_c^2}-\left(\frac{\gamma}{2\pi}\right)^2\right]}{\mu_r} \quad (4)$$

Here γ and γ_0 are the propagation constants in the material and vacuum respectively, and λ_0 is the free space wavelength and λ_c is the cutoff wavelength of the waveguide. The algorithm to extract the complex permittivity and permeability is implemented using the above equations.

REFERENCES

[1] F. Costa, M. Borgese, M. Degiorgi, and A. Monorchio, 'Electromagnetic Characterisation of Materials by Using Transmission/Reflection (T/R) Devices', *Electronics*, vol. 6, no. 4, p. 95, Nov. 2017, doi: 10.3390/electronics6040095.

[2] A. N. Vicente, G. M. Dip, and C. Junqueira, 'The step-by-step development of NRW method', in *2011 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC 2011)*, Natal, Brazil, Oct. 2011, pp. 738–742. doi: 10.1109/IMOC.2011.6169318.

[3] L. Chen, Ed., *Microwave electronics: measurement and materials characterisation*. Chichester: John Wiley, 2004.

[4] A. M. Nicolson and G. F. Ross, 'Measurement of the Intrinsic Properties of Materials by Time-Domain Techniques', *IEEE Trans. Instrum. Meas.*, vol. 19, no. 4, pp. 377–382, Nov. 1970, doi: 10.1109/TIM.1970.4313932.