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A Permittivity Measurement Equipment Based on Oblique Aperture Ridge Waveguide

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***Abstract*-In this paper, a non-contact permittivity measurement device based on oblique aperture ridge waveguide using transmission/reflection method is presented, which is designed to accurately measure the complex permittivity of corrosive liquids and expand the industrial applications of microwave energy. Scattering parameters of the proposed measurement device were simulated at 2.45 GHz and room temperature. The permittivities of the materials to be measured were obtained by artificial neural network algorithm, in which taking the scattering parameters as input. The simulation results are consistent with the setting values, which verifies the accuracy of the measurement. The test tube is used as the container for the object to be tested, which avoids the corrosion of the liquid to the measuring device. The system can also measure the dielectric properties of solids and solid powders at room or high temperature, and has good prospects in the industrial applications of microwave energy.**

I. Introduction

Microwave technology plays a very important role in material for industrial, scientific, and medical applications [1-5]. These applications involve three main characteristics of microwave transmission, reflection, and absorption [6,7]. These three properties are related to the permittivity of a medium. Therefore, it is necessary to understand the permittivity properties and accurately obtain the permittivity of the material for the correct and reasonable use of the material in microwave engineering.

There are different permittivity measurement methods and systems according to different physical forms of media, such as solids, liquids, solid powders, and in different temperature environments.

The measurement methods can be divided into resonant type and non-resonant type [8]. For the high temperature measurement of low loss materials, the measurement accuracy is higher when using the resonant cavity perturbation method, which is commonly used in point frequency measurement [9]. For the measurement of high loss materials, the non-resonant method is widely used. This method has the advantages of wider measurement frequency band range, low requirements to produce samples under measured, and simple system construction.

In general, the permittivity of material is difficult to be measured directly by the equipment. The scattering parameter of the medium can be simulated by software or measured by VNA, and there is a complex relationship between the permittivity and scattering parameter. Artificial neural network (ANN) allows computational models consisting of multiple processing layers to learn data representations with multiple levels of abstraction, and can learn very complex functions [10]. Therefore, we use the ANN to obtain the permittivity of materials through the scattering parameters.

In this paper, a permittivity measurement system of oblique aperture ridge waveguide based on ANN was proposed. The scattering parameters of the proposed measurement device were simulated at 2.45 GHz and room temperature. The permittivity of the materials to be tested were obtained by inversion using ANN algorithm, in which taking the scattering parameters as input. The simulation results are consistent with the setting values, which verifies the accuracy of the measurement. The measurement system can be used to measure the permittivity of materials at high temperatures or during temperature rise, and provides a non-contact measurement method for corrosive liquids.

II. System design

The proposed permittivity measurement system (Fig. 1) has four parts: a network analyzer, a ridge waveguide, two waveguide coaxial converters and two coaxial cables. A network analyzer E8363C is used to measure the scattering parameters when the sample is plugged into the ridge waveguide. The scattering parameters $|S_{11}|$ and $|S_{21}|$ are recorded as amplitudes (in dB), and ϕ_{S21} is recorded as phases (in degrees). For the measurement, the sample to be measured is placed in the oblique aperture ridge waveguide so that the material to be measured is in the electromagnetic field, and the dielectric properties of the object to be measured affect the scattering parameters of the system. The scattering parameters of the system are measured with a vector network analyzer, input to a PC, and the permittivity of the sample are reconstructed using an artificial neural network algorithm.

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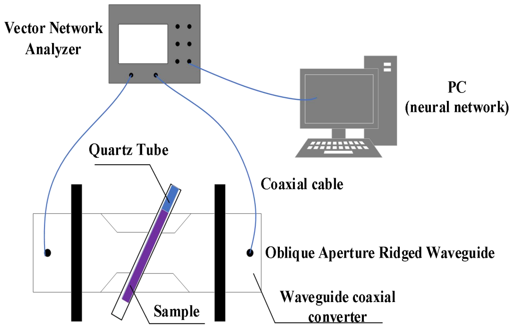


Figure 1.Schematic diagram of measuring system.

A. Core equipment design

The core equipment of the permittivity measurement system is an oblique aperture ridge waveguide, which consists of four parts: a rectangular waveguide, a ridge, an oblique aperture for waveguide testing, and an observation hole, as shown in Fig. 2. Based on the standard BJ22 rectangular waveguide, the wide wall is bent to form a ridge, which allows the electromagnetic field to be concentrated between the two ridges, forming a ridge waveguide. Comparing the scattering parameters of oblique aperture and normal ridge waveguide, the scattering parameters of oblique aperture ridge waveguide have a larger variation range and higher measurement sensitivity within the same loss angle tangent variation. The simulated results of the scattering parameters when the real part of the permittivity of the materials to be measured is varied from 1 to 40 and the loss angle tangent from 0.1 to 0.8 are simulated using the electromagnetic simulation software CST. The simulation results for the oblique aperture ridge waveguide and the normal ridge waveguide[11] with a real part of 25 and a loss angle tangent in the range of 0.1-0.8 are shown in Fig. 3. Comparing the scattering parameters of the oblique aperture and normal ridge waveguide, the scattering parameters of the oblique aperture ridge waveguide vary more in the same loss angle tangent variation interval and have higher measurement sensitivity.

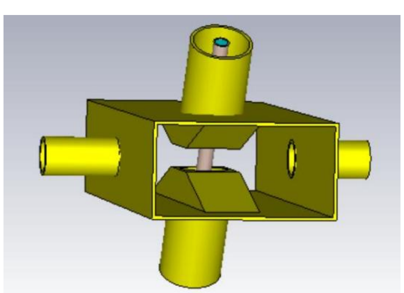
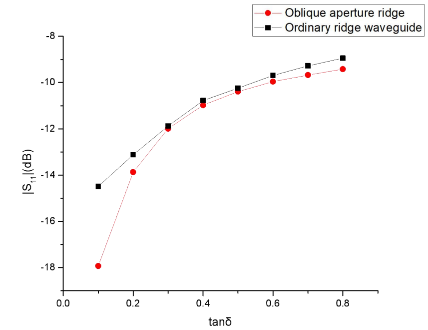
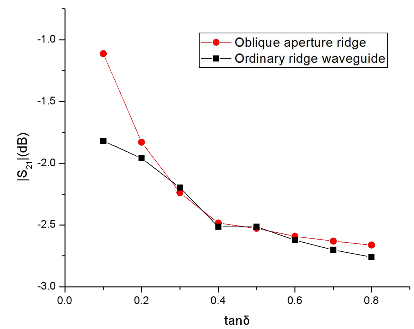


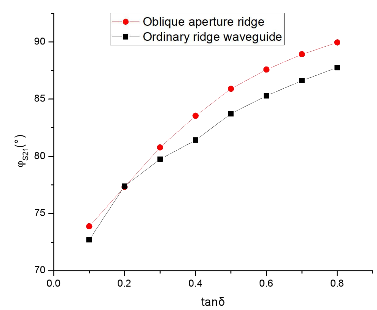
Figure 2. Schematic of oblique aperture ridge waveguide.



(a) Sensitivity comparison results of $|S_{11}|$



(b) Sensitivity comparison results of $|S_{21}|$



(c) Sensitivity comparison results of φ_{S21}

Figure 3. Sensitivity comparison results of ordinary ridge waveguide and oblique aperture ridge waveguide at 2.45GHz.

B. Neural network design

We used an ANN (Fig. 4) to reconstruct the complex permittivity of the material measured by the scattering parameters ($|S_{11}|$, $|S_{21}|$, and φ_{S21}). The network is mainly composed of three parts: one input layer, three hidden layers and one output layer. The input vector of the input layer is the scattering parameter, and the two dielectric characteristic vectors of the output layer are the real part of the permittivity and the tangent of the loss angle. We train the artificial neural network to make it have good accuracy. Some of the simulated data were selected as samples for training the neural network so that the neural network can be used for permittivity reconstruction. The 40 sets of simulation data not used for training were input into the trained neural network, and the predicted mean square errors of the real part of the permittivity and the tangent of the loss angle are all within three percent, indicating that the neural network can be used for permittivity accurate reconstruction of this system. Using artificial neural network algorithm instead of transcendental equation to obtain the permittivity of the medium improves the calculation speed and accuracy, and can realize the real-time measurement of the permittivity of the material. Results are gained very quickly once the network has been trained.

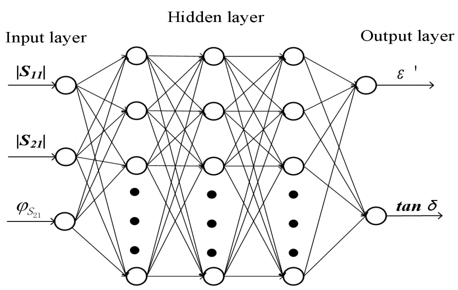


Figure 4. Neural network model.

III. RESULT ANALYSIS

To further validate the accuracy of measuring the permittivity by the system, we randomly selected five sets of permittivity data which the real part was 7, 15, 26, 34 and 40 respectively, the loss angle tangent was 0.6, 0.8, 0.2, 0.4 and 1 respectively. The scattering parameter ($|S_{11}|$, $|S_{21}|$, and φ_{S21}) was calculated using the simulation software CST. Then the scattering parameter calculated is added 1% error to simulate the measurement experiment. The scattering parameter after adding the error is the input of ANN, and the results of the reconstruction of real part and the loss angle tangent are shown in the table I, respectively.

The reconstructing relative errors of both the real part and the loss angle tangent of permittivity are within 5%, which verify that the equipment can be used for permittivity measurements.

TABLE I
EFFECTIVE PERMITTIVITIES OF MATERIALS AT 2.45 GHZ.

Permittivity					
Real part			Loss tangent		
Sim.	Rec.	Error (%)	Sim.	Rec.	Error (%)
7	7.13	+1.86	0.6	0.59	-1.67
15	15.01	+0.07	0.8	0.83	+3.75
26	26.46	+1.77	0.2	0.21	+0.01
34	33.80	-0.59	0.4	0.42	+5.00
40	39.64	-0.90	1	0.96	-4.00

IV. CONCLUSION

In this paper, a permittivity measurement system based on oblique aperture ridge waveguide is designed. And combined with artificial neural network, the permittivity of the material is reconstructed by scattering parameters. The reliability of the system is verified. In addition, the system can be used to measure solids, liquids and solid powders, and the system provides a non-contact permittivity measurement method, which can be used to measure the permittivity of corrosive liquids. This measurement system will have good prospects for applications of microwave energy.

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