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USE OF THE WAVEGUIDE TECHNIQUE TO MEASURE THE ELECTROMAGNETIC PARAMETERS OF MATERIALS

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Abstract: The paper presents and discusses selected simulation and measurement possibilities of an upgraded waveguide measuring stand for testing electromagnetic properties of selected materials (including metamaterials), based on the microwave propagation technique. The stand is equipped with the CST Studio Suite software, which enables modeling and simulation of broadly defined electromagnetic interactions, and the N1500A Materials Measurement Suite module for processing the results of measurements of electromagnetic properties of materials.

Keywords: metamaterials, interaction of electromagnetic radiation with metamaterial structures, waveguide technique, modeling of electromagnetic interactions.

1. INTRODUCTION

Increased interest in new materials and their new applications leads to a fast development of research technology and measuring methods. Research on metamaterials, i.e. materials with unique electromagnetic properties that do not naturally occur in nature, is a part of this trend. The electromagnetic properties of materials are expressed by such parameters as coefficients of the absorption, reflection and transmission of electromagnetic radiation, and of electrical and magnetic permeability.

An example of a single metamaterial structure is a small metal circuit consisting of resonating cavities and conductive pathways that interact with variable magnetic and electric fields. The dimensions of individual metamaterial structures are comparable to the wavelengths, and entire structures can form one-, two- or three-dimensional networks. By properly selecting the geometry, dimensions, and material parameters of metamaterial structures, their electromagnetic properties can be significantly changed. Metamaterials are characterized by a high absorption coefficient in a specific frequency range. This feature makes metamaterial structures a universal component for building larger electromagnetic radiation absorbers. Microwave radiation absorbers can be used, among other things, to reflect or absorb unwanted high power electromagnetic radiation (HPEM). The absorbent properties of certain metamaterial structures are desirable for protection of civil and military electronic systems against unwanted radiation from external sources, e.g. those used by terrorists [Wolarz 2007; Chakraborty 2013; Singh and Marwaha 2015].

Research on metamaterials is undoubtedly a new and attractive research topic. Modern test stands make it possible to perform comprehensive and complex examinations of many physical problems related to the properties of metamaterial structures.

This paper presents and discusses the research capabilities of a stand for testing the electromagnetic properties of materials, including metamaterials, which consists of two independent modules. The first module is used to simulate the electromagnetic properties of metamaterials using the CST Studio Suite software. The second module is an experimental set for measuring the electromagnetic parameters of materials with basically unknown electromagnetic parameters and for verifying the results of simulations of the electromagnetic properties of metamaterials with known material parameters determined using the CST Studio Suite software.

2. TEST STAND DESCRIPTION

As mentioned earlier, the test stand consists of two modules:

- a computer simulation module in the CST Studio Suite environment;
- a module to measure the electromagnetic parameters of materials, more specifically to determine the coefficients of the material scattering matrix in the waveguide chain and to calculate on their basis such material parameters as electrical and magnetic permeability and coefficients of absorption (A), reflection (R), and transmission (T) using the N1500A Materials Measurement Suite software from Keysight.

The computer module and the module for the measurement of electromagnetic parameters of materials form a comprehensive test stand for simulating the electromagnetic properties of metamaterials with known material parameters and for verifying the simulation results in experimental measurements of electromagnetic parameters.

2.1. Computer simulation module in the CST Studio environment

This module consists of the CST Studio Suite software developed by the company CST (Computer Simulation Technology). This program is used to model and simulate the electromagnetic (EM) interaction of electromagnetic radiation with designed objects. The CST Studio enables the design, simulation, analysis, and optimization of single material elements, as well as complex electronic devices over a wide frequency range. The ability to design components from different types of materials (e.g. lossy, nonlinear, plasma, ferrite, anisotropic, and non-homogeneous) and to simulate many physical problems (e.g. the Computational Fluid Dynamics (CFD) software in fluid mechanics) makes the software a versatile and attractive tool to select prototypes for further experimental research. Numerical methods make it possible to analyze the mechanisms and effects of the interaction of electromagnetic radiation with individual objects and with entire electronic and electrical systems. Such a possibility significantly shortens the time of research by reducing the number of tested prototypes and reduces the costs of experimental research [www.cst.com].

The CST Studio Suite software makes it possible to choose two types of numerical analysis: Frequency Domain and Time Domain [www.cst.com].

Numerical calculations in the Frequency Domain enable creating a grid from tetrahedrons with curved sides for simulating 3D objects [www.cst.com].

The Transmission-line matrix (TLM) method and the Finite Integration Technique (FIT) method available only in the CST Studio Suite are used for numerical calculations in the Time Domain. An additional possibility available only in the CST Studio Suite software is to perform a simulation involving up to three different materials in one simulation cell [www.cst.com].

2.2. Stand equipped with Keysight's N1500A Materials Measurement Suite software for measuring the electromagnetic parameters of materials

A diagram of a waveguide stand for measuring material dispersion matrix coefficients is shown in Figure 1.

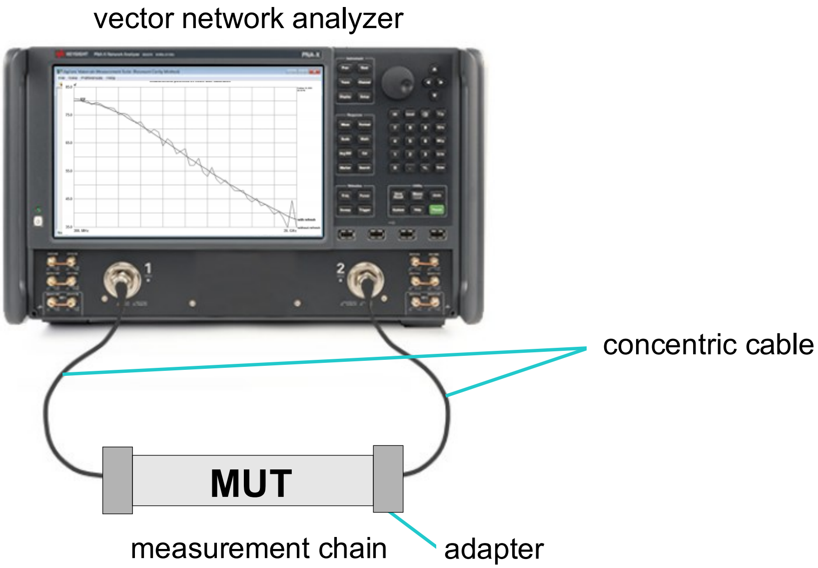

Fig. 1. A diagram of a waveguide test stand for measuring the properties and parameters of microwave electronic components

The measuring stand consists of a Keysight N5225A network vector analyzer (purchased as a part of the RIDAM grant) connected by means of coaxial cables and dedicated adapters to the measurement chain in which the Materials Under Test (MUT) are placed. The measurement chain can be either a rectangular waveguide (in our case WR-90 or WR-62) or a coaxial line (in our case with 7 mm inside diameter). The selection of the measurement chain depends on the type of material to be tested and the microwave frequency range used to test the material. The use of a waveguide and a coaxial line makes it possible to extend the range of frequencies used for the testing. The network analyzer is equipped with calibration kits that contain dedicated holders to place the material under test in the waveguide channel or the coaxial line. This solution eliminates measurement errors that could be caused by introducing elements into the system that are incompatible with a network analyzer.

The Keysight N5225A network analyzer is a high-end 2-port vector network analyzer operating in the frequency range of 10 MHz to 50 GHz. It is equipped with calibration kits suitable for the supported frequency range and the standard of the used measurement wires. Dedicated calibration kits enable correct adjustment of the network vector analyzer parameters before the actual measurements are performed and have a decisive impact on the measurement error values.

The capabilities of the test stand with the Keysight N5225A network vector analyzer are extended by the N1500A Materials Measurement Suite software. The Keysight Technologies N1500A Materials Measurement Suite makes it possible to determine material parameters from the measured dispersion matrix values. The N1500A Materials Measurement Suite uses the well-known NRW algorithm proposed by Nicolson, Ross, and Weir [Nicolson and Ross 1970; Weir 1974; www.literature.cdn.keysight.com].

This algorithm makes it possible to determine the combined electric and magnetic permeability and the coefficients of absorption, reflection, and transmission from the values of the dispersion matrix coefficients. The values of the matrix coefficients, on the other hand, are determined in experimental research using the Keysight N5225A network vector analyzer.

The software is compatible with the Keysight N5225A network vector analyzer and contains an algorithm for correcting measurement errors that result from undesirable effects caused by air gaps in the places where individual components of the measurement chain are connected. The errors resulting from the presence of air gaps are the source of the largest measurement errors in transmission lines. The algorithm also corrects systematic errors by using dedicated calibration and measurement sets and calibration procedures.

The measuring stand extended with the N1500A Materials Measurement Suite computation software enables measurements of scattering matrix coefficients and coefficients of absorption and transmission of materials over a wide frequency range of 45 MHz to 18 GHz.

3. RESULTS OF PRELIMINARY TESTS

As a part of the preliminary tests, a prototype of a single planar metamaterial structure SRR (Split-Ring Resonator) was simulated in the CST Studio environment. The metamaterial structure was tested in terms of its absorption and reflection properties in the microwave range of 1 GHz to 20 GHz.

The examined metamaterial structure consisted of two 35 μm thick square copper rings placed on a FR-4 dielectric substrate. The dimensions of the structure were 30 x 30 x 5 mm. A diagram of the structure is shown in Figure 2.

As a part of the simulation procedure, the SRR structure was placed in a virtual flat electromagnetic wave propagation path. As a result of the simulation, the frequency characteristics of the coefficients of absorption (A), transmission (T) and reflection (R) of the SRR structure as well as the combined electric and magnetic permeability coefficients were obtained.

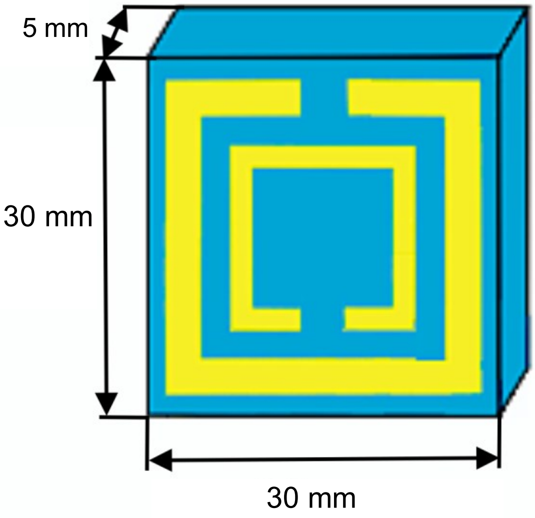

Fig. 2. A geometric diagram of the SRR structure

The obtained numerical results of electromagnetic parameters of the studied structure were published in the paper [Budnarowska et al. 2019]. These results will be verified in an experimental chain for measuring the electromagnetic parameters of materials.

Currently, preliminary experimental works are being carried out (calibration of the measurement chain, preparation of the SRR structure, and placing the SSR structure in a rectangular waveguide) that will result in verification of the results of the simulation of the SRR structure performed by the CST Studio Suite software.

4. CONCLUSIONS

The stand described in this communication makes it possible to perform comprehensive and complex simulation and experimental research on the electromagnetic properties of selected materials (including metamaterials), based on the microwave propagation technique.

Equipping the stand with calibration sets containing, among others, waveguides and coaxial lines extended the test range, providing the possibility to place the tested materials in the chain of the microwave measuring system.

The use of two pieces of software, i.e. CST Studio and Keysight Technologies N1500A Materials Measurement Suite, made it possible to model, analyze, and optimize potential material prototypes and to determine the combined electrical and magnetic permeability based on the values of the dispersion matrix coefficients for further experimental research and processing of the results obtained.

As a part of the preliminary tests, a model of a single planar metamaterial structure of SRR was developed for further experimental research.

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