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A New Method for Testing an Isotropic and An-isotropic Materials Using Three-probes Based on Free-Space Gaussian Beam Method

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***Abstract*—A novel concept of three-probe RF scanner system for the characterization of the isotropic/an-isotropic materials and the testing of the engineered structures is proposed. The proposed system covers a frequency range from 1 GHz to 8 GHz. The proposed system tests the material using the free-space Gaussian Beam method where probes capture full scattering matrix data as a function of frequency and incident angle. This system is designed, implemented, and integrated with LabView to provide automated measurement capabilities. The durability of the system concept is validated by performing the characterization of RT-5880 at oblique incident angles for 7.5 GHz. Furthermore, s-parameters measurements of an-isotropic engineered material (a frequency selective surface) at oblique incident angle are conducted.**

***Index Terms*—An-isotropic, artificial dielectric layer, engineered structures and material characterization.**

I. Introduction

Nowadays, characterization of different materials is very critical in the development of modern RF devices. The conventional material is assumed to be uniform and traditional measurement methods suffice; however, for engineered structures having an-isotropic constitute, uniform performance may not occur. The constitutive parameters of these an-isotropic materials are a function of the direction of the impinging field. To measure these materials off broadside traditional methods, such as a waveguide [1] or two-probe free-space characterization (Figure 1a) [2], cannot be used.

Much work has been done for characterizing the uniform and conventional materials, using free space method [2]–[5]. The s-parameters of the frequency selective surfaces are obtained using different types of free-space methods [6]. However, all these free-space methods have limitation not only in the frequency domain but also in the angle domain. For lower frequency, such as at S-band frequencies, larger area is required due to the large size (around 2 feet) of the lenses [2]. In case of oblique incident angles, such lenses are extremely difficult to manuever. Furthermore, only transmitted power can be measured. To extract the precise constitutive parameters of the material, both reflected and transmitted power are required, thus, making it unsuitable for an-isotropic materials.

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To completely characterize an an-isotropic material, a system must be able to capture full scattering matrix data over all possible incident angles. This leads to the concept of a novel three-probe RF automated system. This system requires the addition of a third probe that rotates in tandem with the material under test (MUT), as shown in Figure 1b, allowing the capture of both the transmitted and reflected components of the impinging wave and thus the application of material characterization algorithms. This system allows accurate measurements of engineered structures over a wide range of incident angles for a frequency range from 1 GHz to 8 GHz. In addition to the hardware, a control system using LabView is developed to allow rapid and accurate material characterization.

II. Hardware Setup

The proposed three-probe RF scanner, as shown in Figure 1c, utilizes six aluminum rails, each with mounted trolley. All the linear actuators have a NEMA 23 stepper motor attached that is used to position the trolleys and allows the entire measurement process to be automated. Three of the rails are mounted horizontally around a single axis where the material under test (MUT) is also mounted on a velmex B5900 rotary table. Two of these three rails are fixed and opposite to each other around the material. The third rail is controlled by a velmex B4800 rotary table that allowed to rotate freely around the sample. The other three vertical rails are mounted on a trolley of each horizontal rail. These three rails can position their trolleys vertically and upon each trolley a probe is mounted. This allows for each of the three probes to move both up/down and closer/farther from the sample independently.

Copper Mountain Planar 804/1 VNA is interfaced with the designed software. This VNA has only two ports, whereas three probes are required to take the transmission and reflection measurements, specifically for oblique incident angle measurements. Therefore, an RF solid state relay (STDP) is used to switch the second port between the second and third probes to receive the transmitted and reflected waves, respectively. To communicate with this switch, an Arduino Uno is used to control a solid state relay that delivered the required 24 V to operate the switching action. All of the stepper motors that drive the linear actuators are controlled by two TinyG CNC controller boards. Additionally, limit

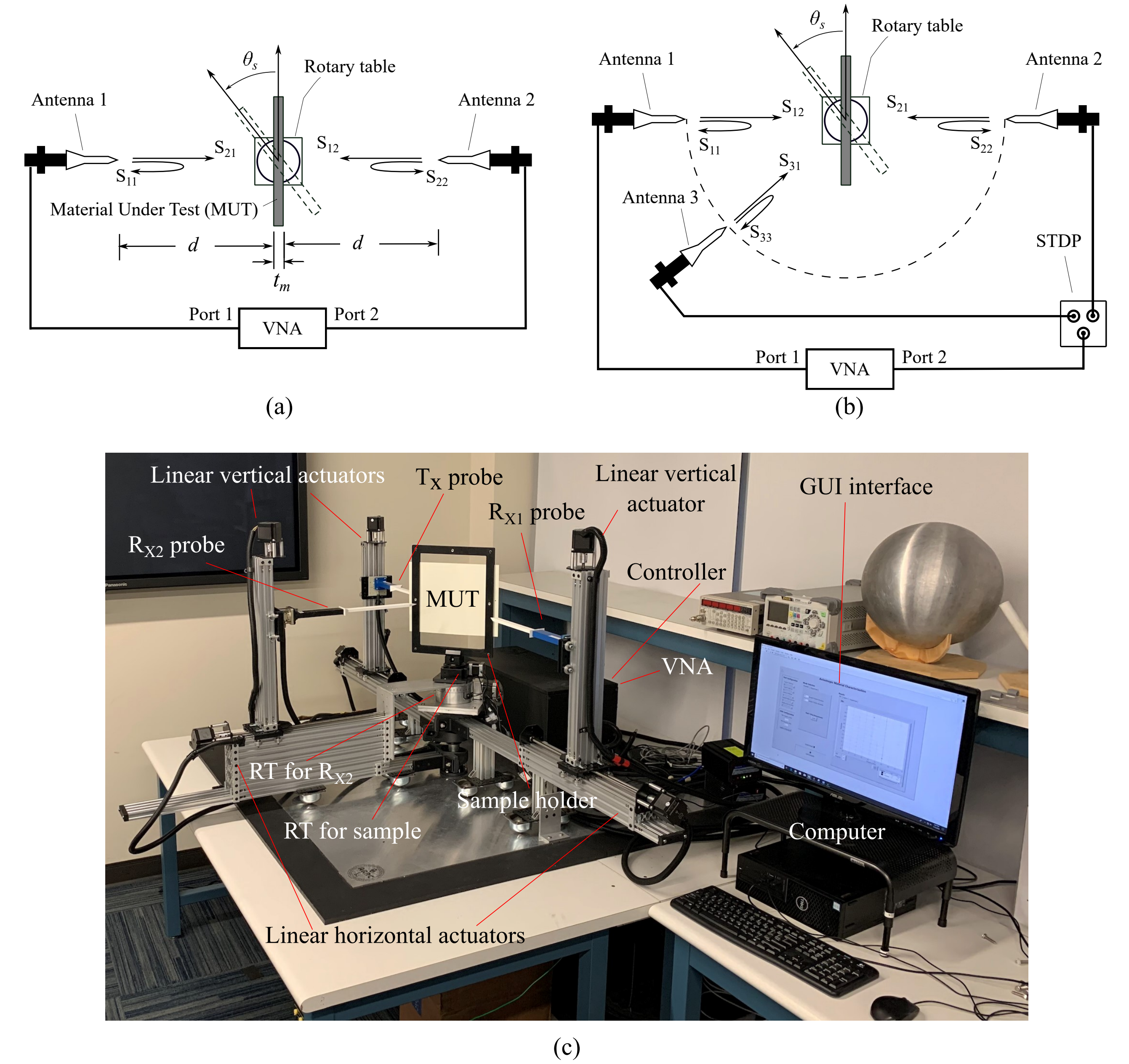

Fig. 1. (a) Schematic of conventional two-probe RF scanner. (b) Schematic of proposed three-probe RF scanner. (c) Implementation of proposed three-probe RF scanner system.

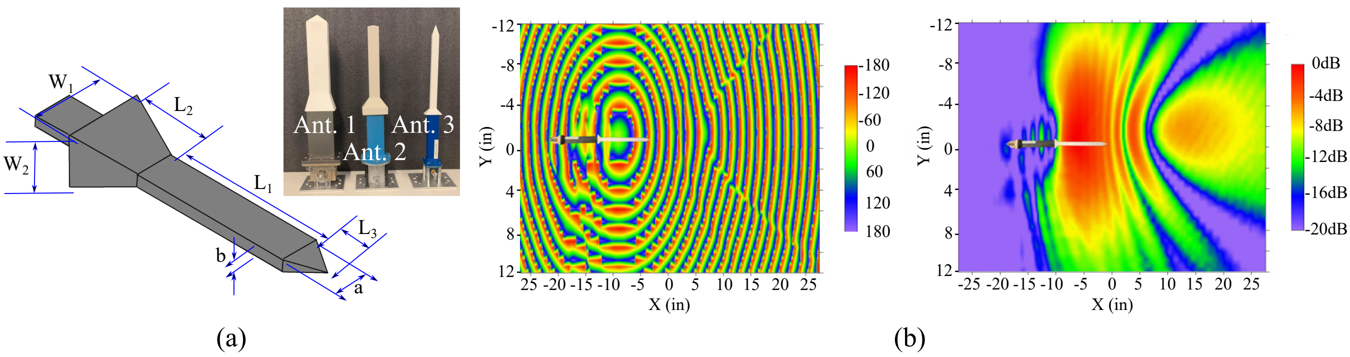

Fig. 2. (a) Dielectric resonator antennas (DRA) at different frequencies for the proposed system. (b) Phase and magnitude 2D-patterns of side-view DRA.

switches are mounted on all of the linear actuators at known positions to allow the system to automatically home itself and prevent damage to the system.

TABLE I
DIMENSIONS OF THE ANTENNAS (IN MM).

Antenna	L_1	L_2	L_3	W_1	W_2	a	b
1	210	50	20	85	40	57	26
2	205	50	5	75	35	31	14
3	200	16.5	29	50	23	20	8.5

TABLE II
PERFORMANCE OF THE ANTENNAS.

Antenna	Freq. bandwidth (GHz)	Gain (dB)	BW_{3dB}
1	2.5 - 3.5	12.54	34
2	4.0 - 5.0	12.91	26
3	7.0 - 8.0	12.99	16

The dielectric resonator antennas integrated with an open ended wave-guide (OEWG) are designed for S- and C-bands, as shown in Figure. 2. These types of antennas are very useful for this application because they have narrow and Gaussian beamwidth along with a plane-wave region closer to the antenna, as shown in Figure. 2c . These antennas are design using a PLA material of ε_r=3.2 in the Makerbot Z18 3D printer. The detailed parameters of all these antennas are depicted in Table I and their performance are depicted in Table II. This eliminates the use of conventional lenses [2] and causes a reduction in the size of the entire testing system specially at low frequencies.

III. SOFTWARE SETUP

The proposed setup is controlled using a newly designed interface using LabView. This interface has several key features include VNA configuration, manual mechanical control, measurement configuration, calibration and homing, system status visualization, data visualization, and data saving utilities.

An automated calibration procedure is also implemented in the proposed system,. Transmission-Reflection-Line (TRL) calibration technique is used for broadside measurements (frequency sweep) [7]. Whereas, Transmission-Reflection (TR) calibration technique is used for angular sweep [2], [8]. For both calibration techniques, the first step is homing all of the rails (horizontal and vertical) using the installed limit switches. Then the probes are moved to the initial position w.r.t frequency of measurement. For TRL calibration, the transmission standard will be measured at first. Then the line standard will be measured by moving the probes λ/4 away from each other. To measure the last reflection standard, the system will prompt the user to input the reflector between the probes. Finally the system applies and saves the calibration state. In case of TR calibration, the transmission standard will be measured that will be used for all incident angles. Then the system will prompt the user to input the reflector for the measurement of reflection standard. The reflector and third probes moves in synchronization w.r.t each incident angle.

The last procedure that needs to be implemented for material characterization is the extraction algorithm, which is Nicholson-Ross-Wier algorithm [9], [10].

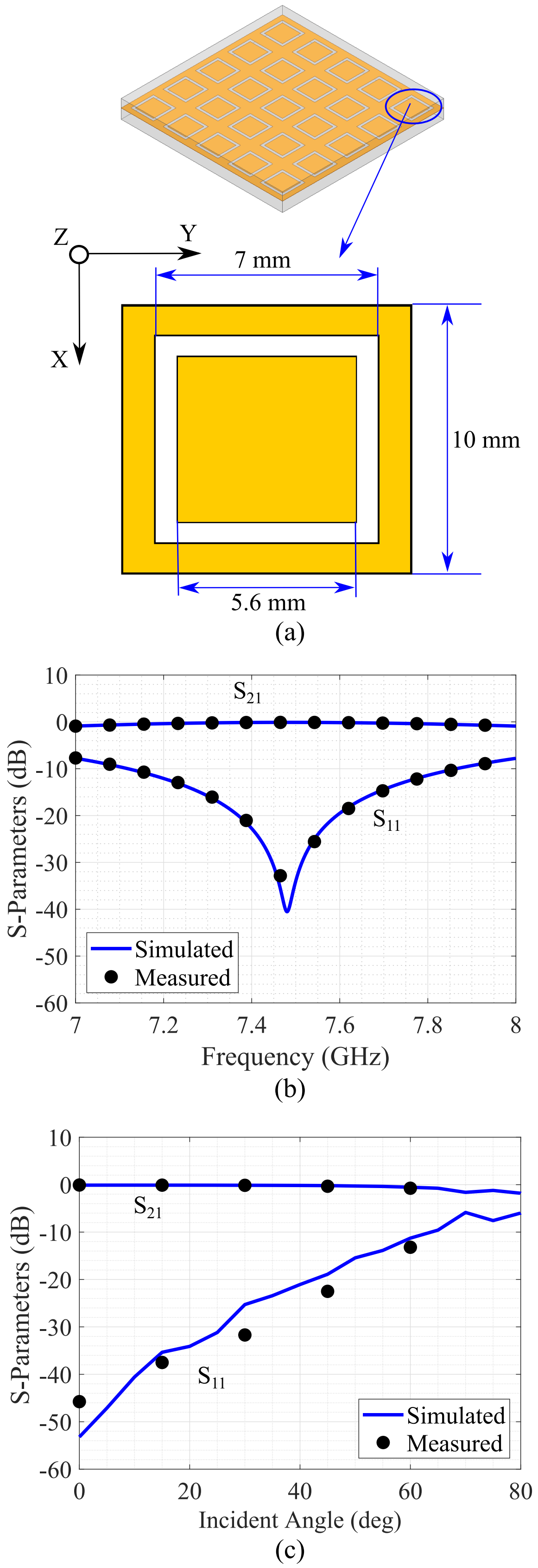

Fig. 3. Frequency Selective surfaces (FSS). (a) Design schematic. (b) Simulated and measured S-parameters in frequency domain. (c) Simulated and measured S-parameters in angle domain.

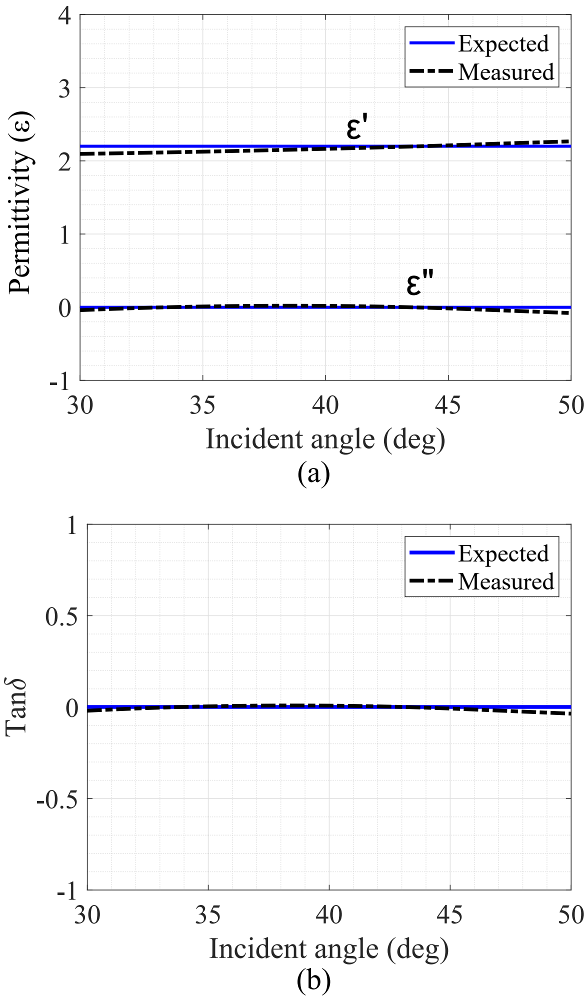

Fig. 4. Expected and measured electrical properties of RT-5800 at oblique incident angles. (a) Permittivity. (b) Tangent loss.

IV. Results

To show the performance of the proposed three-probe RF system, a commercially available material (RT-5880) is characterized. Moreover, frequency selective surfaces (FSS) is fabricated and measured. Frequency Selective Surfaces is tested for a frequency band from 7 GHz to 8 GHz and at oblique incident angle for 7.5 GHz frequency as shown in Figure. 3. The measured S_{21} is deviated from the simulation by an absolute error 0.01 dB in frequency domain and 0.2 dB in the incident angle domain. It can be seen in Figure. 3c, the error increases as the angle increases. This occurs due to small size of sample that causes edge diffractions. RT-5880 is characterized at oblique incidences and the errors are quantified, as shown in Figure. 4. When the MUT (RT-5880) is tested over oblique incident angles, the maximum permittivity error of 0.1, permeability error of 0.06 and tangent-loss error of 0.009 are observed. This is most likely due to diffractions from the edges of the MUT and direct transmission errors, which occur when a portion of the beam does not pass through the MUT and instead propagates directly to the other R_X probe which increases the measured magnitude.

V. Conclusion

A new three-probe RF scanner system is developed to characterize the isotropic/an-isotropic materials and to measure the artificially designed RF structures for a frequency range from 1 GHz to 8 GHz. The proposed system is automated which provides fast and accurate measurements. To show the performance of the proposed system, measurements of engineered structures (FSS) and characterization of the commercially available materials is conducted. All electrical parameters (ε, μ and $tan\delta$) of RT-5880 has maximum error accuracy of 0.1 at oblique incident angles for 7.5 GHz frequency. Furthermore, measurements of the S-parameters (S_{21}) of an-isotropic engineered material (a frequency selective surface) shows errors less than 0.01 dB at normal incidence and less than 0.2 dB at oblique incident angle.

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References

[1] K. Y. You and K. G. Sotirios, "Materials characterization using microwave waveguide system," Microwave systems and applications,pp. 341–358, 2017.

[2] J. W. Schultz, "Focused Beam Methods Measuring Microwave Materials in Free Space," 2012.

[3] D. K. Ghodgaonkar, V. V. Varadan, and V. K. Varadan, "A free-space method for measurement of dielectric constants and loss tangents at microwave frequencies," IEEE Transactions on Instrumentation and measurement, vol. 38, no. 3, pp. 789–793, 1989.

[4] D. Ghodgaonkar, V. Varadan, and V. Varadan, "Free-space measurement of complex permittivity and complex permeability of magnetic materials at microwave frequencies," IEEE Transactions on instrumentation and measurement, vol. 39, no. 2, pp. 387–394, 1990.

[5] F. H. Wee, P. J. Soh, A. Suhaizal, H. Nornikman, and A. Ezanuddin, "Free space measurement technique on dielectric properties of agricultural residues at microwave frequencies," in2009 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC).IEEE, 2009, pp. 183–187.

[6] L. Chen, B. Yang, H. Yan, and S. Wen, "Test technology for frequency selective surface material in RF integration," in2013 5th IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications. IEEE, 2013, pp. 206–208.

[7] G. F. Engen and C. A. Hoer, "Thru-Reflect-Line: An improved technique for calibrating the dual six-port automatic network analyzer," IEEE Transactions on Microwave Theory and Techniques, vol. 27,no. 12, pp. 987–993, dec 1979.

[8] M. Kaniecki, E. Saenz, L. Rolo, R. Appleby, and O. Breinbjerg, "Scattering-parameter extraction and calibration techniques for RF free-space material characterization," in 8th European Conference on Antennas and Propagation, EuCAP 2014. IEEE, apr 2014, pp. 1093–1097.

[9] A. M. Nicolson and G. F. Ross, "Measurement of the intrinsic properties of materials by time-domain techniques," IEEE Transactions on Instrumentation and Measurement, vol. 19, no. 4, pp. 377–382, nov 1970.

[10] W. B. Weir, "Automatic measurement of complex dielectric constant and permeability at microwave frequencies," Proceedings of the IEEE,vol. 62, no. 1, pp. 33–36, 1974.