On the Dielectric Permittivity of 3-D Printed Biocomposite Cubes Using Two Different Coaxial Probe Measurement Methods

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***Abstract*—The volume of electronic (e-)waste is at a new high with the ever-increasing use of traditional printed circuit boards (PCBs) worldwide. A possible solution to tackle such a challenge is to use biocomposite materials for manufacturing printed circuit boards. However, knowledge on the dielectric profile of such biocomposite materials is required for designing a radio frequency (RF) circuit. For this work, the permittivity was determined from 1 GHz to 6 GHz for three unique industrially available biocomposite materials. Specifically, two different types of industrial standard coaxial probes were used to measure the dielectric constants of three biocomposite materials, Buzzed, Entwined, and WoundUp. The measured data was presented and validated using a comparative analysis.**

I. Introduction

Popular methods for prototyping PCBs, such as the photolithography technique or prototyping milling process, have been established for research and industrial purposes for many years now. Due to the low production cost and availability of engineering to fit a larger number of circuits in limited real-estate, almost every electrical circuit is being realized today through PCBs. However, a substantial number of PCBs are currently discarded every year as e-waste, possibly resulting in polluting the environment by depositing hazardous chemicals and heavy metals. Moreover, de-soldering and burning PCBs for landfilling also increases the carbon footprint. With this current trend, researchers already predicted that the total amount of e-waste would generate up to 50 metric tons by the end of the year 2018 [1]. Contrary to regular PCBs, researchers from academy and industries have recently proposed different biocomposite materials for designing electrical circuits with their applications in medical [2], wireless [3], and agricultural industries [4]. Now unlike the subtractive methods for creating PCBs, lately, additive manufacturing techniques (3-D printing) offer more freedom to engineers in selecting a variable resolution, choices of materials, and in controlling the inhomogeneous distribution for designing the base of the PCBs [5], to name a few. Particularly, the recent advancements in 3-D printing filaments with various flexible, semi-rigid and biocomposite materials introduced versatile RF applications, from designing conformal RF circuits [6] and antennas [7] to developing eco-friendly biocomposite PCBs

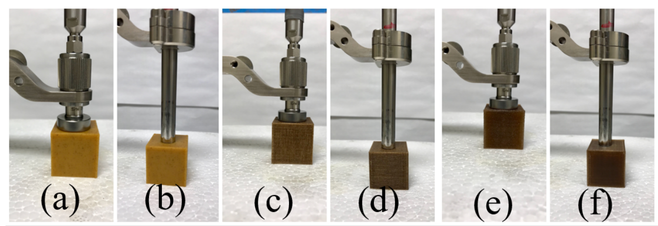

Fig. 1. Measuring dielectric constants of 3-D printed cubes using High-Temperature Probe (HTP) and Performance Probe (PP). Samples: Buzzed under HTP (a) and PP (b), Entwined under HTP (c) and PP (d), and WoundUp under HTP (e) and PP (f). The ambient temperature was 18°C.

[8]. The results reported in [9] and [10] by the authors laid the foundation of a successful realization of RF propagation using such new biocomposite materials. These materials are additive manufacturing-friendly and partially bio-degradable. Thus, there is a need for a database of dielectric profiles of such materials for RF applications. The objective of this paper is to contribute to this database. For the first time, this paper presents the measured dielectric profiles of three distinct biocomposite materials using two different industrial dielectric measurement probes in the RF frequency spectrum from 1 GHz to 6 GHz which covers most of the current cellular, WiFi, and Industrial, Scientific and Medical (ISM) bands.

II. Fabrication of the 3-D Printed Prototypes

First, identical cuboid prototypes of 2.54 cm×2.54 cm×2.54 cm with 100% infill were additively manufactured for the materials under test, viz. Buzzed [11], Entwined [11], and WoundUp [11]. Table I summarizes the base elements and 3-D printing settings for prototyping each cube.

III. Measuring Dielectric Profiles

The probes used in the measurements of dielectric profiles of the samples were the Keysight High-temperature Probe (HTP) 85070-2036 and the Keysight Performance Probe (PP) 85070-60010 [12]. Both systems used the open-ended coaxial line method for measuring the dielectric constant. While taking measurements, the two probes were kept in an identical

TABLE I
MATERIAL DETAILS AND SETTINGS FOR ADDITIVE MANUFACTURING

Materials	Base Element	Temp (°C)	Speed (mm/s)	Layer Height (mm)	3-D Printer
Buzzed	Dried distiller grains	215	40	0.10	MakerBot Replicator
Entwined	Hemp fiber	215	40	0.10	MakerBot Replicator
Wound Up	Coffee	215	40	0.10	MakerBot Replicator

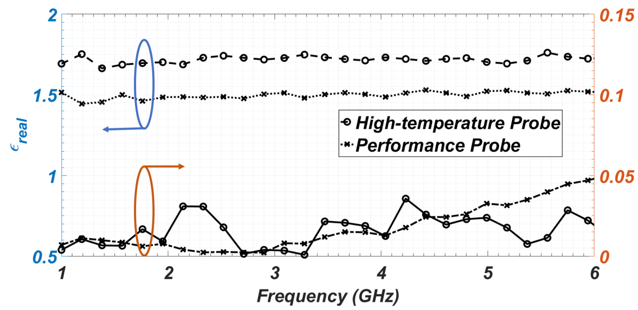

Fig. 2. Measured relative permittivity and loss tangent of material: Buzzed.

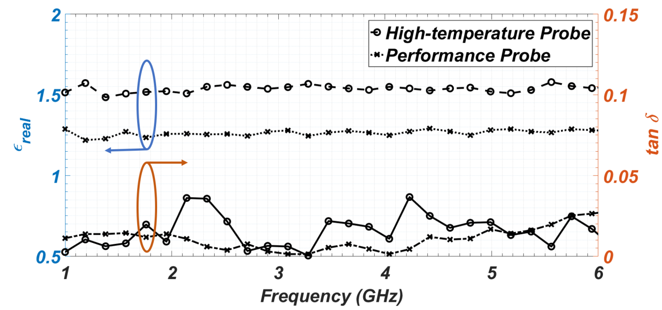

Fig. 3. Measured relative permittivity and loss tangent of material: Entwined.

environment and calibrated using industrial standard distilled water at 18°C. The vector network analyzer (VNA) used was a Keysight E5071C. The VNA and both dielectric probes were calibrated for 1 GHz to 6 GHz. Finally, measurements were performed for each material using both probes and the results are presented in Figs. 2 - 4. Table II presents the average measured dielectric profiles using both probes for the three biocomposite materials from 1 GHz to 6 GHz.

TABLE II
MEASURED AVERAGE DIELECTRIC PROPERTIES FROM 1 GHZ TO 6 GHZ

Materials	ϵ_{real} (HTP)	$\tan\delta$ (HTP)	ϵ_{real} (PP)	$\tan\delta$ (PP)
Buzzed	1.8	0.03	1.6	0.04
Entwined	1.6	0.03	1.4	0.04
Wound Up	1.9	0.03	1.7	0.04

IV. CONCLUSION

The measured data from the two different probes was observed to be fairly agreeing with each another considering the reported accuracy levels for both probes [12].

ACKNOWLEDGEMENT

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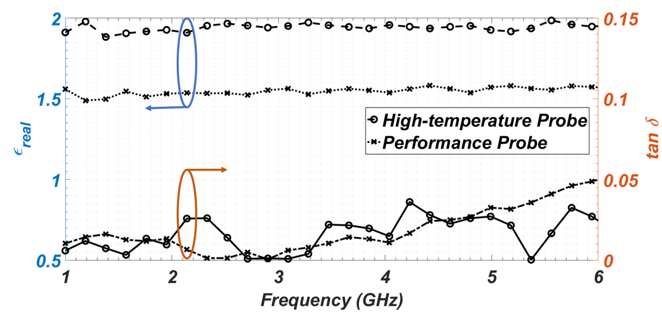

Fig. 4. Measured relative permittivity and loss tangent of material: WoundUp.

REFERENCES

[1] C. P. Balde, V. Forti, V. Gray, R. Kuehr and P. Stegmann, *The Global E-waste Monitor 2017: Quantities, flows and resources*, Tokyo & Bonn: United Nations University, 2017.

[2] P. F. Kiser and P. Tresco, "Biodegradable and biocompatible peg-based poly (ester-urethanes)," U.S. Patent 11/578,321, April 15, 2005.

[3] N. W. Anderson and Deere & Company, "Non-toxic, biodegradable sensor nodes for use with a wireless network," U.S. Patent 8,063,774, November 22, 2011.

[4] C. Bauer-Reich, J. Hoey, R. Sailer, N. Schneck and C. Ulven, NDSU Research Foundation, "Biodegradable soil sensor, system and method," U.S. Patent Application 14/760,867, January 15, 2014.

[5] S. Moscato, R. Bahr, T. Le, M. Pasian, M. Bozzi, L. Perregrini, and M. M. Tentzeris, "Infill-dependent 3-D-printed material based on ninjaflex filament for antenna applications," *IEEE Antennas and Wireless Propagation Letters, 15*, pp. 1506-1509, 2016.

[6] J. J. Adams, E. B. Duoss, T. F. Malkowski, M. J. Motala, B. Y. Ahn, R. G. Nuzzo, J. T. Bernhard, and J. A. Lewis,"Conformal printing of electrically small antennas on three dimensional surfaces," *Advanced Materials*, Vol. 23, no. 11 pp. 1335-1340, January 2011.

[7] S. Roy, S. Sajal, and B. D. Braaten, "A phase correction technique based on spatial movements of antennas in real-time for designing self-adapting conformal array antennas," *Microwave and Optical Technology Letters,* vol. 59, no. 12, pp. 3002-3010, 2017.

[8] V. K. Guna, G. Murugesan, B. H. Basavarajaiah, M. Ilangovan, S. Olivera, V. Krishna, and N. Reddy, "Plant-based completely biodegradable printed circuit boards," *IEEE Transaction on Electron Devices*, Vol. 63, no. 12, pp. 4893-4898, 2016.

[9] S. Roy, M. B. Qureshi, S. Asif, S. Z. Sajal and B. D. Braaten, "A study of microstrip transmission lines on substrates created using additive manufacturing and flexible or semi-rigid filaments," *16th Annual IEEE International Conference on EIT*, May 2017, Lincoln NE, USA.

[10] M. B. Qureshi, S. Roy, S. Asif, S. Z. Sajal, Chad Ulven and B. D. Braaten, "On using biocomposite filaments to additively manufacture substrates for microstrip transmission lines," *16th Annual IEEE International Conference on EIT*, May 2017, Lincoln NE, USA.

[11] c2renew inc. [online] Available: www.c2renew.com, Jan. 2018.

[12] Keysight Tech. [online]. Available: www.keysight.com, Jan. 2018.