Proposal Research Topic: A Dielectric Permittivity Sensor Based on Inverted Microstrip/3D-Printing Hybrid Technology

Student: Sofia Rustioni, *Student Member, IEEE*

Faculty Mentor: Maurizio Bozzi, *Fellow, IEEE*

***Abstract*—The proposed research topic consists in the development of an innovative sensor for the dielectric characterization of liquid materials. The sensor is based on a section of inverted microstrip line, combined with a channel where the liquid material flows. The structure is fabricated by using a hybrid technology, which integrates the standard printed circuit board technique (to implement the inverted microstrip) with the additive manufacturing (to realize the channel). The dielectric characteristics of the liquid material are retrieved from the variation of the frequency response of the structure (with respect to the case of no liquid). Different materials will be adopted for validating the performance of the sensor, and the retrieved dielectric properties of the materials will be compared with data obtained from commercial devices.**

***Keywords*—Additive manufacturing, hybrid technology, inverted microstrip, microwave sensor.**

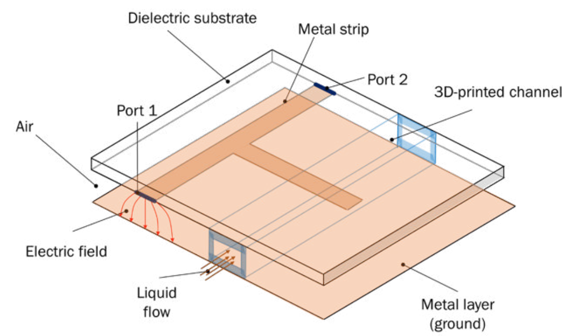

Fig. 1. Schematic view of the dielectric permittivity sensor, based on an inverted microstrip line combined with a 3D-printed channel.

I. Introduction

The development of microwave sensors for the determination of the dielectric properties of materials is a research topic that exhibits growing interest in recent years [1]-[3]. These sensors are adopted for a wide range of uses, including the biomedical applications, the environmental monitoring, the control of the food chains, and many more. With the advent of the Internet of Things (IoT), the request for wireless sensors is becoming even more relevant.

These sensors permit to determine the complex permittivity of dielectric materials through the measurement of the frequency response. Various techniques can be adopted to retrieve the relative dielectric permittivity and the loss tangent of solid, liquid, and gaseous materials from the measured scattering parameters [3], [4].

In most applications, the major requirements combine good accuracy and sensitivity with simple design and low-cost manufacturing. To meet all these requirements, many solutions based on planar structures as well as on additive manufacturing have been adopted [1]-[4]. Hybrid solutions, which combine planar technologies and additive manufacturing, have also been investigated: they allow to exploit the best features of each individual solution, offer additional design flexibility, and usually lead to simple manufacturing [5].

The research topic proposed here aims at the implementation of a sensor for the characterization of the dielectric properties of liquids, based on a hybrid manufacturing technique, which adopts an inverted microstrip realized by standard printed circuit board (PCB) process combined with a channel for the liquid under test, implemented by additive manufacturing. While the inverted microstrip allows for low loss and easy connector mounting, the 3D-printed channel provides ample design flexibility and the optimization of the amount of liquid and of input/output interface for the liquid pipes. Additionally, the proposed solution exhibits a relatively low cost, thus making it suitable to possible commercial applications.

II. Project Description

The proposed sensor is based on a section of inverted microstrip line with a quarter wavelength open ended stub, combined with a channel where the liquid material flows (Fig. 1). This solution is particularly interesting for the implementation of a microwave sensor, thanks both to its topology and to the manufacturing flexibility. In fact, the electric field distribution of the fundamental mode of the inverted microstrip is mainly located in the air gap between the metal strip and the ground plane (Fig. 1). This field distribution presents several and significant advantages: first of all, propagation losses are reduced compared to the classical microstrip line, as the electric field is mainly in the air and the dielectric loss is practically zero. For this reason, the dielectric substrate plays a marginal role in the propagation mechanism, and consequently there are no requirement of using an extremely low-loss (i.e., expensive) dielectric substrate. Moreover, the channel, where the liquid under test (LUT) flows, is located in the air gap, under the stub, here the electric field is more intense thus this is extremely beneficial in terms of sensitivity.

The variation on the dielectric properties of the different liquids flowing in the channel below affects the frequency response of the stopband, as exemplified in (Fig.2).

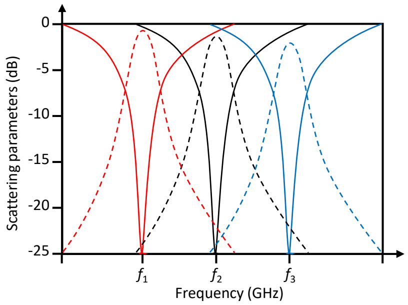

Fig. 2. Example of frequency response of the sensor: reflection coefficient $|S_{11}|$ (dashed lines) and transmission coefficient $|S_{12}|$ (soldi lines) in the case of liquids with different dielectric properties.

The sensor operates at around 2.45GHz in the Industrial, Scientific and Medical band (ISM).

The input/output inverted microstrip line has been designed to exhibit a characteristic impedance of 50 Ω.

The performance of the sensor was tested by using different liquid materials, namely acetone, isopropanol and deionized water. The dielectric characteristics of the LUTs, used to perform the full-wave simulations, were measured with the Dieletric Probe Kit Keysight N1501A, at a temperature of 29° and they are shown in Table 1.

III. Measurement

At first, a fitting between simulations and measurements, with no liquid material inside the channel, has been performed to retrieve, with a fine tube, the dielectric properties of the 3D printed channel (εr = 2.25, tanδ = 0.007). The simulated and measured results have been compared in Fig.3.

The difference between the simulated and measured results in the stopband central frequency is 5.5MHz with isopropanol, 9MHz and 12MHz with acetone and with the deionized water respectively, leading to a maximum of 10% difference.

The experimental results validate the working principle of the designed prototype.

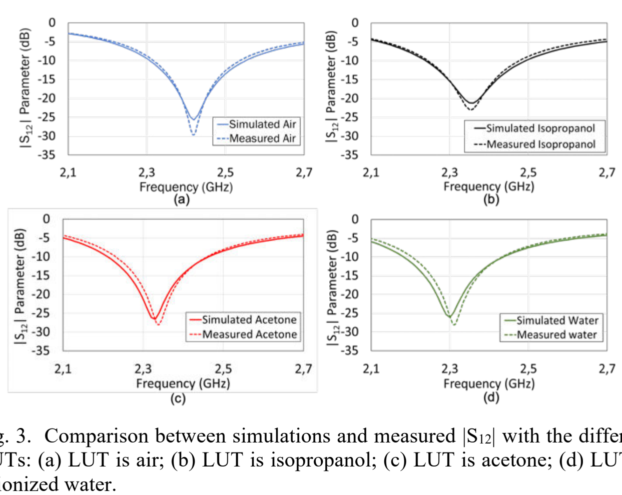

Fig. 3. Comparison between simulations and measured $|S_{12}|$ with the different LUTs: (a) LUT is air; (b) LUT is isopropanol; (c) LUT is acetone; (d) LUT is deionized water.

TABLE 1. Dielectric properties of the LUTs extracted with a commercial Dielectric Probe Keysight N1501A

MATERIAL	εr	tanδ
Isopropanol	5.1	0.687
Acetone	21.4	0.033
Deionized water	76	0.12

II. Future Plans And Impact of MTT-S Scholarship Program

In the near term, I plan to continue my education by pursuing a graduate degree in Electrical Engineering, focusing on microwave theory and techniques.

Looking further ahead, I envision myself contributing to the industry as a specialist in microwave engineering. My long-term aspiration is to become a recognized expert in the field, hoping to stay connected to the academic world through collaborative research efforts.

The MTT-S Scholarship has significantly influenced my career trajectory, providing me the opportunity to attend the IMS Conference in Washington DC.

I expect MTT-S conference to be a deeply enriching experience, both professionally and personally. I'm eager to meet and connect with other students, researchers, and industry professionals who share my interest. I'm really looking forward to diving deep into the latest advancements in microwave theory and techniques at the conference, listening to experts present their groundbreaking technologies.

IV. Conclusion

The project described in this document aims to implement a sensor for determining the electrical characteristics of liquid materials, utilizing a hybrid technology that combines planar components and 3D-printed structures. A more detailed article on the subject is currently being developed, which will provide further insights and analysis on the methods used and the results obtained with this innovative technology.

References

[1] T. Chretiennot, D. Dubuc and K. Grenier, "A Microwave and Microfluidic Planar Resonator for Efficient and Accurate Complex Permittivity Characterization of Aqueous Solutions," *IEEE Trans. Microwave Theory Techn*., vol. 61, no. 2, pp. 972-978, Feb. 2013.

[2] A. Ebrahimi, J. Scott and K. Ghorbani, "Ultrahigh-Sensitivity Microwave Sensor for Microfluidic Complex Permittivity Measurement," *IEEE Trans. Microwave Theory Techn*., vol. 67, no. 10, pp. 4269-4277, Oct. 2019.

[3] G. M. Rocco, M. Bozzi, D. Schreurs, L. Perregrini, S. Marconi, G. Alaimo, and F. Auricchio, "3D-Printed Microfluidic Sensor in SIW Technology for Liquids Characterization," *IEEE Trans. Microwave Theory Techn*., vol. 68, no. 3, pp. 1175-1184, Mar. 2020.

[4] M. Alipour Masoumabad, N. Delmonte, L. Silvestri, L. Perregrini, and M. Bozzi, "A Simple Technique for Liquid-Liquid Percentage Determination Using Single-Frequency Amplitude Measurements," *IEEE Microwave and Wireless Technology Letters*, 2023 (available online).

[5] I. Piekarz, J. Sorocki, N. Delmonte, L. Silvestri, S. Marconi, G. Alaimo, F. Auricchio, and M. Bozzi, "Microwave-Microfluidic Sensor in Hybrid 3-D Printing and Laminate Technology for Chemicals Monitoring from Differential Reflection," *IEEE MTT-S International Microwave Symposium* (IMS 2021), Atlanta, Georgia, USA, 21-25 June 2021.