

A UWB Near-Field Contact-less Sensor for Liquid Dielectric Spectroscopy

Ali Pourghorban Saghati, *Student Member, IEEE*, and Kamran Entesari, *Senior Member, IEEE*

Abstract—A 3-10 GHz contactless sensor for time domain liquid dielectric spectroscopy is discussed in this report. The sensor setup is based on utilizing two printed UWB Vivaldi antennas coupled to each other at their radiative near-field region with the material-under-test (MUT) placed in the middle. The sensor setup is fabricated with an overall size of $15.6 \times 6.1 \text{ cm}^2$. The proposed sensor is utilized in a time-domain spectroscopy system which includes pulse generator, transmitter, compact contact-less sensing unit, and the receiver. The over-all system shows mean-squared error of less than 0.81%, and 2.47% for ϵ' and ϵ'' characterization, respectively, compared with theory.

Index Terms—Contact-less sensing, dielectric spectroscopy, time-domain (TD), ultra-wideband (UWB) system.

I. INTRODUCTION

BROADBAND dielectric spectroscopy (BDS) is a powerful technique for characterization of materials properties with a broad range of industrial, scientific and medical applications such as oil exploration and processing, food and drug safety, chemical sensing, and disease diagnosis, to name a few [1], [2]. Dielectric constant is an important measure for the polarity of organic chemicals such as solvents used in chemical industry. However, such microwave techniques require the sensing element to be in direct contact with the material-under-test (MUT). As a result, the sensing element might need to be replaced after each measurement, which can impose reliability and repeatability issues. On the other hand, hybrid integration of both fluidics and sensing circuitry on a single board makes the fabrication procedure more cumbersome [2].

Free-space far-field sensing technique can be considered as a remedy to achieve contactless sensing [3]. However, the dimensions of the required antennas, and the overall setup for such techniques are considerably large at microwave frequencies, and therefore, impractical for characterizing low-volume liquid materials. Moreover, since the sensors are operating in the far-field with relatively large dimensions, special attention is required in calibration and testing to deal with multiple reflections/transmissions from the MUT (electromagnetic bouncing) and also multiple reflections from the surrounding environment issues, both of which increase the inaccuracy of the detection. Therefore, even though this method is well-established for laboratory research, efforts are still required for miniaturized contact-less sensing applications at microwave frequencies.

This report discusses the efforts made to address the aforementioned issues by employing a miniaturized contact-less sensing element consisting of a fluidic module carry-

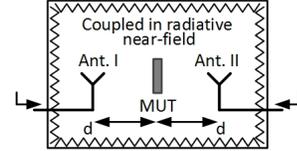


Fig. 1. Conceptual setup of the near-field coupled contact-less sensor setup.

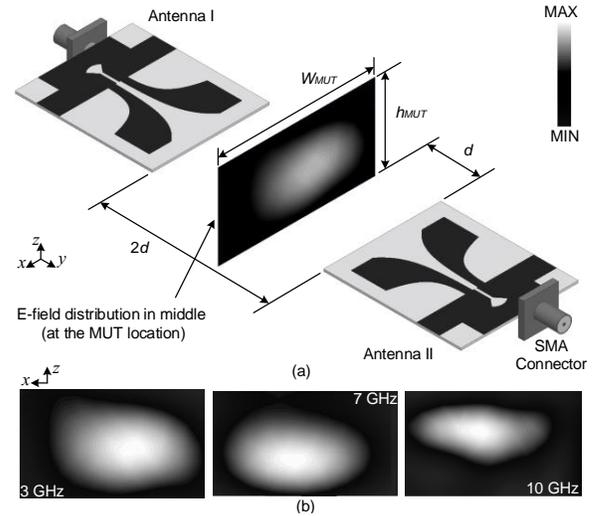


Fig. 2. (a) The two near-field coupled antennas faced each other, and the E-field distribution is shown in middle and at the position of MUT at $f = 3 \text{ GHz}$, and (b) the E-field distribution in a plane in between the two antennas where the MUT is located at different frequencies. The design values are: $W_{MUT} = h_{MUT} = 51 \text{ mm}$, and $d = 30 \text{ mm}$.

ing material-under-test (MUT) located in the radiative near-field region of two ultra-wideband (UWB) antennas with nearly constant group delay over the entire 3-10 GHz broad bandwidth in microwave range. The proposed sensor is also utilized in a system-level time-domain (TD) liquid dielectric spectroscopy system, which the measurement results show mean-squared error of less than 0.81%, and 2.47% for ϵ' and ϵ'' characterization, respectively, compared with theory [4]–[6].

II. UWB CONTACT-LESS SENSOR & TIME-DOMAIN SYSTEM-LEVEL IMPLEMENTATION

In order to achieve contact-less broad-band microwave sensing suitable for TD material characterization with a compact setup size, and relatively low volume of the sample, near-field sensing is proposed as a solution. Fig. 1(a) shows the conceptual setup of the proposed near-field solution. Two antennas are coupled in their near-field region while the MUT is placed in between. The setup is surrounded with

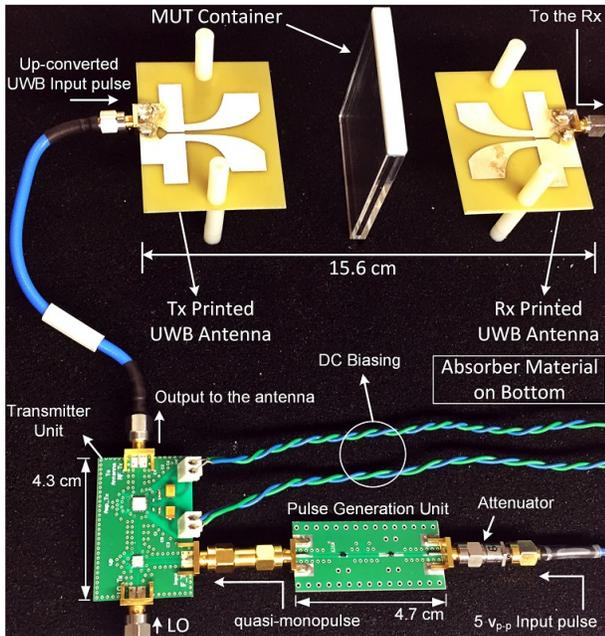


Fig. 3. Fabricated setup of the proposed contact-less UWB spectroscopy system.

absorbing materials (ECCOSORB AN) to provide an anechoic environment. In the proposed setup shown in Fig. 1(a), the distance between the two antennas (d) needs to be adjusted accurately, so that the two antennas are coupled to each other in their Fresnel regions, and therefore, have minimum effect on each other's return loss characteristics. As a result, the overall size of the setup depends on the targeted frequency range, antenna size, and its Fresnel region distance, which determines the value for d .

The antenna type for the setup shown in Fig. 1(a) requires to satisfy two main criteria. First, the system design is based on covering the complete 3-10 GHz UWB frequency range. Second, the antenna element needs to be non-dispersive in order to be able to detect the dispersive properties of solely the MUT. In this setting, the Vivaldi antenna is one of the best candidates due to its broad bandwidth, low cross-polarization, and constant group delay. The two vivaldi antennas are faced to each other and placed at $2d = 60$ mm apart from each other so that they are coupled in their radiative near-field considering the frequency range of 3-10 GHz. The E-field distribution is plotted in between the two antennas, and where the MUT needs to be placed, and shown in Fig. 2 at different frequencies.

The proposed sensor is first introduced in [5], where both liquid materials and thin (mm-range) solid dielectric slabs are detected based on S_{21} measurements as a proof of concept. The proposed contact-less setup is then utilized in [4], where a combined frequency domain (FD)/ time domain (TD) technique is proposed for liquid material characterization. To enhance the detection accuracy in this work, a new baseband signal is generated by combining multiple up converted Gaussian signals. This system is tested for xylene, ethanol, and methanol, and the measurement results are verified comparing

with the direct measurements of vector network analyzer (VNA). Finally, the proposed sensor is utilized in [6], where a pure time-domain material characterization is implemented. In this case, the proposed system, shown in Fig. 3, includes a transmitter, a compact contactless sensing unit, and a receiver. A picosecond pulse generator unit in the transmitter delivers a quasi-monocycle pulse with 3.5-GHz 10-dB bandwidth to an up-converter and then an amplifier. The transmitter unit provides the 3-10-GHz excitation pulse based on utilizing a direct up-conversion architecture. The excitation pulse is transmitted to the receiver through the sensing unit. The TD data are captured for each MUT using DSA91304A infinium oscilloscope as the receiver, and finally the fast Fourier transform of the measured data is extracted in MATLAB. The system shows the worst case mean-squared error (MSE) of 1.92% for ϵ' and 3.84% for ϵ'' characterization.

III. FELLOWSHIP IMPACT & CAREER PLAN

Receiving the IEEE MTT-S Graduate Fellowship award is an honor that has impacted my professional life in different ways. To name a few, first, it was a great opportunity to attend the International Microwave Symposium (IMS) 2017, in Honolulu, HI, where I was able to present my work, and receive highly constructive feedbacks while meeting folks and colleagues from all around the world with wide different backgrounds of academia and industry. Second, I believe the fact that the hard work is being seen and recognized by highly talented people around the world, boosted my motivation and increased my standard expectations of my self to even more expand my experience in the field of microwave engineering. To me, working in highly fast-paced industry-related projects is highly valuable, while keeping the close relationship with academia is a must. I believe the recognition of receiving the MTT-S fellowship award will help me to better demonstrate my capabilities and my significant interest to the field of radio-frequency, microwave, and millimeter-wave engineering. I hope I can have continual contribution to this field and to the IEEE MTT society.

REFERENCES

- [1] K. Entesari, A. A. Helmy, and M. Moslehi-Bajestan, "Integrated systems for biomedical applications: Silicon-based rf/microwave dielectric spectroscopy and sensing," *IEEE Microwave Magazine*, vol. 18, no. 5, pp. 57–72, July 2017.
- [2] A. P. Saghati, J. S. Batra, J. Kameoka, and K. Entesari, "A metamaterial-inspired wideband microwave interferometry sensor for dielectric spectroscopy of liquid chemicals," *IEEE Transactions on Microwave Theory and Techniques*, vol. PP, no. 99, pp. 1–14, 2017.
- [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, Jun 1989.
- [4] R. E. Ghiri, A. P. Saghati, E. Kaya, and K. Entesari, "A 3-10 GHz contact-less complex dielectric spectroscopy system," in *2017 IEEE MTT-S International Microwave Symposium (IMS)*, June 2017, pp. 621–623.
- [5] A. P. Saghati and K. Entesari, "A uwb near-field contactless sensor for solid and liquid material characterization," in *2017 IEEE International Symposium on Antennas and Propagation USNC/URSI National Radio Science Meeting*, July 2017, pp. 901–902.
- [6] R. E. Ghiri, A. P. Saghati, E. Kaya, and K. Entesari, "A miniaturized contactless uwb microwave system for time-domain dielectric spectroscopy," *IEEE Transactions on Microwave Theory and Techniques*, vol. 65, no. 12, pp. 5334–5344, Dec 2017.