Development of an Automated System to Obtain Dielectric Property Measurements of Materials Using an Open-Ended Coaxial Probe

Ciaran Geaney, *Student Member, IEEE*, Jeremie Bourqui, and Elise Fear, *Senior Member, IEEE*

Abstract—**Dielectric property measurements are important to the development and validation of biomedical imaging technologies. Aspects of a dielectric property measurement system at the University of Calgary were automated and a user interface was developed to make the system easier to use and to make measurements more consistent. The results of the modified system were compared with those of manual measurements to validate the new software.**

Index Terms—**Dielectric property measurement, test automation, microwave imaging**

I. INTRODUCTION

THE Tissue Sensing Adaptive Radar (TSAR) group at the University of Calgary develops microwave imaging hardware, signal processing algorithms, and full prototype systems primarily for breast cancer detection and bone imaging applications. The development of these technologies and assessment of their performance relies on knowledge of the dielectric properties of tissue and bone, and the materials used to model them. In order to measure the dielectric properties of materials, namely real permittivity and conductivity, the TSAR group uses a system comprised of an open-ended coaxial probe and a Vector Network Analyzer (VNA) [1]. The test system is pictured in Fig. 1. As accurate and consistent measurements of material properties are necessary, it was desired to automate the existing measurement system as much as possible and make it easier to use.

The existing system requires two reflection measurements: one with the probe radiating freely in air (as shown in Fig. 1), and one with the probe surface in contact with the surface of, or if possible immersed in, the material of interest. The two measurements are then processed by de-embedding the probe and using a Rational Function Model (RFM) to obtain the complex permittivity of the material [1]. The real permittivity ε' and conductivity σ can then be determined as functions of

Ciaran Geaney received his BSc from the University of Calgary, Canada and is currently pursuing an MASc at the University of Toronto, Canada (email: ciaran.geaney@mail.utoronto.ca)
Dr. Elise Fear is a professor at the University of Calgary, Canada (email: fear@ucalgary.ca) and Jeremie Bourqui is a research engineer in her group (email: bourquij@ucalgary.ca). }

frequency from the complex permittivity ε from (1). The data processing code was implemented in MATLAB by previous TSAR group students.

$$\varepsilon = \varepsilon' - j\varepsilon'' = \varepsilon' - j\frac{\sigma}{\omega} \qquad (1)$$

Without the user interface, the typical measurement procedure is:

1. Set up VNA measurement parameters and time-gating
2. Perform a standard 1-port VNA calibration for reflection measurements
3. Measure the air S11
4. Measure the material S11
5. Copy data from VNA memory to a USB key
6. Transfer measurement data to another computer, format it, and perform post-processing to view permittivity results
7. If desired, fit the measurement data to a Debye or Cole-Cole dispersion model
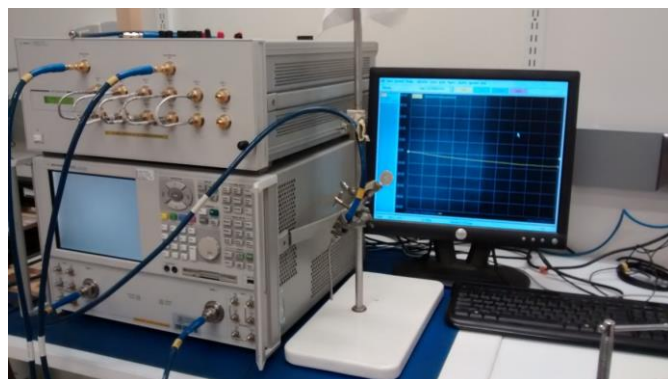

Fig. 1. Dielectric property measurement system

The methodology for fitting the dispersion models is shown in [2], and the software to implement this was developed by previous University of Calgary students.

II. IMPLEMENTATION

The user interface and control software was developed using LabVIEW, and to control the VNA, a General Purpose Interface Bus (GPIB) connection was used. For ease of use by lab members, the software was designed to be used in a

similar manner to other TSAR projects. A screenshot of the developed user interface is shown in Fig. 2.

With regard to the procedure listed above, steps 1 to 4 required user interaction. Some steps, such as calibrating the VNA and aligning the material under test require physical connections to be made and could not be automated. However, the interface allows for users to set the VNA measurement parameters and guides them through the calibration process. This is useful, as all measurement control can be done through a single interface. Time-gating was automatically set up.

Data processing and exporting tasks, steps 5 to 7 above, were automated. This was done by interfacing the LabVIEW control software with MATLAB. For convenience, both the raw and processed data are exported after a measurement session in standardized text files and an Excel summary workbook.
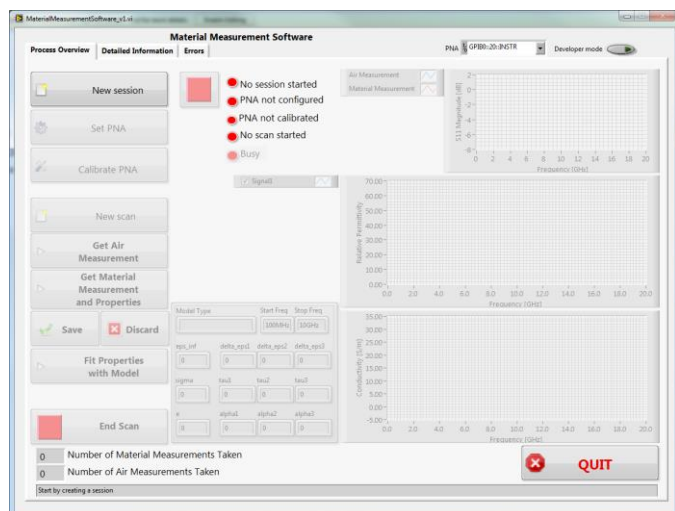

Fig. 2. Screenshot of user interface

Features were also added to give users more flexibility in measurement, such as measurement averaging and the ability to select what data to export. The new system allows for users to view material properties immediately after taking S-parameter measurements. In the previous system the properties could only be viewed after measurement data had been transferred and post-processed in another location, meaning that if mistakes were made during measurement they could not be immediately corrected.

III. VALIDATION TESTING

Before the system could be used for measurements for research purposes, its results had to be validated. To do this, two sets of property measurements were taken of a tap water sample: one with the developed software and one without it. One measurement from validation testing is shown in Fig. 3. Tap water was used for convenience. The two sets of data matched very closely, with any discrepancies likely resulting from random error, as the two measurements were taken separately.
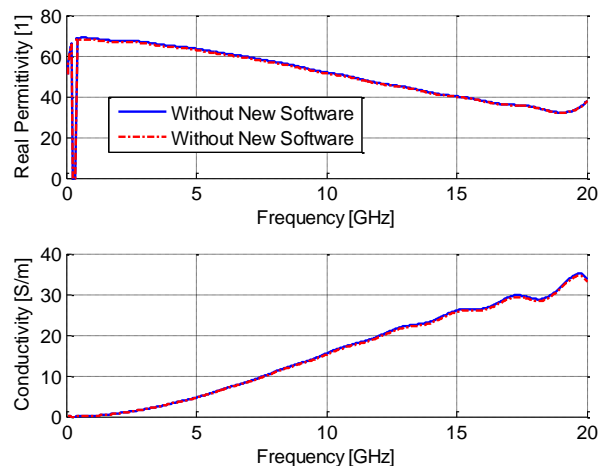

Fig. 3: Comparison between one set of dielectric property measurements of tap water with and without the developed software.

IV. FUTURE WORK

As consistency and documentation of measurements is critical to research, methods to automatically record measurement conditions could be implemented. For example, a camera could be triggered when a probe measurement is taken, or the environmental conditions of the laboratory could be recorded. Another area that could be explored is more accurate dispersion modelling. Multipole Debye or Cole-Cole fitting could be performed, or alternate models could be investigated.

V. CONCLUSIONS

An easy to use user interface for a dielectric property measurement system was developed, and tasks such as data processing and exporting were automated. The system was demonstrated to lab members and validation testing was performed. Areas for future work were identified.

VI. ACKNOWLEDGEMENTS AND FUTURE PLANS

I would like to thank IEEE MTT-S for the scholarship and for supporting undergraduate research and project work. I would also like to thank Dr. Elise Fear for her support and mentorship, and Jeremie Bourqui for his guidance and practical advice throughout the project. Through exposure to microwave engineering research during my duration with the TSAR group I was inspired to pursue graduate school, and have started a Masters program at the University of Toronto where I am researching new multi-beam reflector antennas for satellite applications. Following this, I would like to work in industry and possibly pursue a PhD after gaining some industry experience.

REFERENCES

[1] D. Popovic et al., "Prevision Open-Ended Coaxial Probes for In Vivo and Ex Vivo Dielectric Spectroscopy of Biological Tissues at Microwave Frequencies," *IEEE Trans. Microw. Theory Techn., vol. 53, no. 5, pp. 1713–1722,* May, 2005.
[2] M. Lazebnik, et al., "Highly Accurate Debye Models for Normal and Malignant Breast Tissue Dielectric Properties at Microwave Frequencies," *IEEE Microw. Compon. Lett., vol. 17, no. 12, pp. 822-824,* Dec., 2007.