Antenna Calibration Technique for Estimation of Dielectric Properties of Biological Tissues

David C. Garrett, *Student Member, IEEE,* Jeremie Bourqui, *Member, IEEE,* and Elise C. Fear, *Senior Member, IEEE*

***Abstract*— The estimation of the dielectric properties of biological tissues at microwave frequencies are useful for various applications including biomedical imaging and radio frequency dosimetry. However, few existing techniques are suitable for *ex vivo* tissue property estimation due to the inherent heterogeneity and complex shape of tissues, and no existing methods are well-suited for *in vivo* tissue property estimation due to the layered nature of human tissue. This study presents a method of average dielectric property estimation using an antenna calibration technique, where permittivity and conductivity are estimated between 3-8 GHz.**

***Index Terms*—Dielectric measurement, calibration, microwave imaging, ultra-wideband antennas**

I. Introduction

THE estimation of dielectric properties – permittivity and conductivity - at microwave frequencies has long been investigated for applications in agriculture, material sciences, and circuit technology. Methods such as resonant cavities, transmission lines, and reflection-based techniques are common in the literature [1]. However, for *in vivo* biomedical applications, none of these techniques are convenient due to the heterogeneous nature of biological tissues and the requirement to conform with the shape of the human body. Free-space techniques have been investigated using antennas, but are only suited to measurements of planar, homogeneous materials. The open-ended coaxial probe is commonly used for dielectric property estimation of *ex vivo* biological tissues. However, due to its shallow sensing depth, its application to *in vivo* measurements is limited to surfaces such as the skin and tongue.

The estimation of bulk dielectric properties is of interest to our group for applications in background property estimation for biomedical imaging [2] and for tissue sensing in applications such as bone health monitoring [3]. The properties of tissues are primarily dominated by the contrast between fat (low permittivity and conductivity) and water content (high permittivity and conductivity). For instance, in microwave breast imaging the dielectric properties provide insight into the tissue composition, where adipose tissue has much lower properties than fibroglandular and tumorous tissue.

Here we propose an antenna calibration technique with the objective of estimating bulk dielectric properties of biological tissues. This technique and system allows for convenient estimation of the permittivity and conductivity of tissues with thickness ranging from approximately 20 – 60 mm, as validated in simulation and measurement with tissue-mimicking samples for frequencies between 3-8 GHz.

This work was supported by the IEEE MTT-S Undergraduate/Pregraduate Scholarship Program. The authors are with the Department of Electrical and Computer Engineering at the University of Calgary.

II. Methods

The ultra-wideband, dielectric-loaded antennas in [4] are used to perform microwave measurements in contact with tissues. The measurement configuration is shown in simulation in Figure 1 a), and the signal flow graph used in the calibration procedure is shown in Figure 1 b).

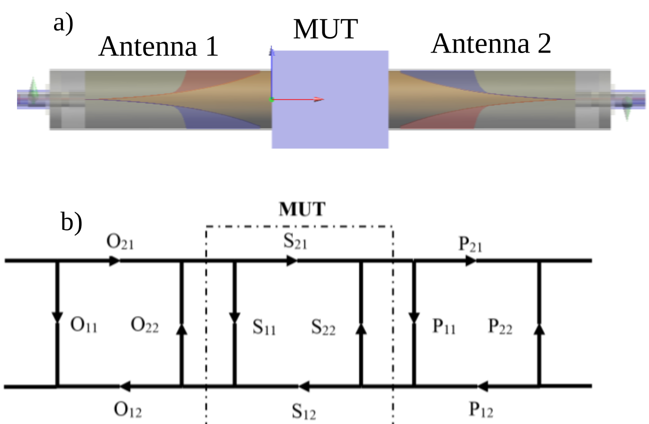

Figure 1. Antenna transmission system: a) in simulation, b) signal flow graph used during the calibration derivation

A calibration procedure is adapted from the Gate-Reflect-Line (GRL) technique introduced in [5]. Since the antennas are to be in direct contact with the tissues the calibration equations are modified accordingly. The Reflect procedure is thus performed with a planar conducting plate in contact with each antenna, and the Thru procedure is performed with both antennas in contact with one another. Two calibration matrices, **O** and **P**, are derived through analysis of the signal flow graph for the two calibration procedures. O_{11} and P_{22} are derived through time-domain gating of the transmitted signal, where reflections due to the radiating antenna are isolated. The microwave response of the tissue is isolated once **O** and **P** are known. A technique based on the Nicolson-Ross-Weir (NRW) method [6] is then applied to estimate the permittivity and conductivity. Full derivation of this technique is not shown here.

III. Results

This technique was first validated using models ranging in properties expected in biological tissue, where the mixtures described in [7] were simulated and measured. Error boundaries were found to be generally within 10%, which approaches the accuracy of the open-ended coaxial probe. Measurements performed on *ex vivo* porcine bone tissues are presented in [8]. Estimated properties of the heterogeneous tissue are found to be reasonable, where the estimated properties lie between literature values for the bone marrow and cortical (hard) bone, the two major constituents of the tissue. Conductivity estimates are not shown here but are found to be slightly overestimated since the radial spreading of the microwave signal emulates loss in the tissue, but still provide insight into the tissue properties.

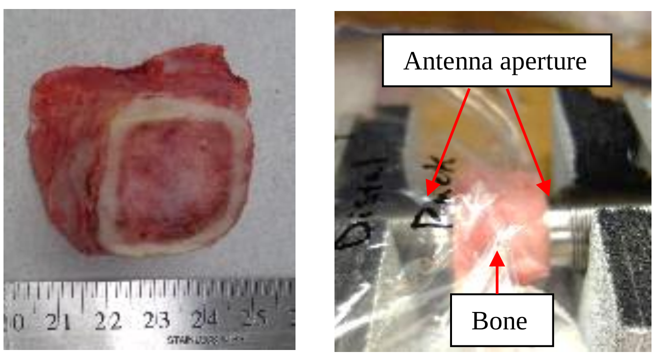

Figure 2. Left: the porcine femur excision. Right: performing the measurement of the excision in a plastic bag using the antenna system

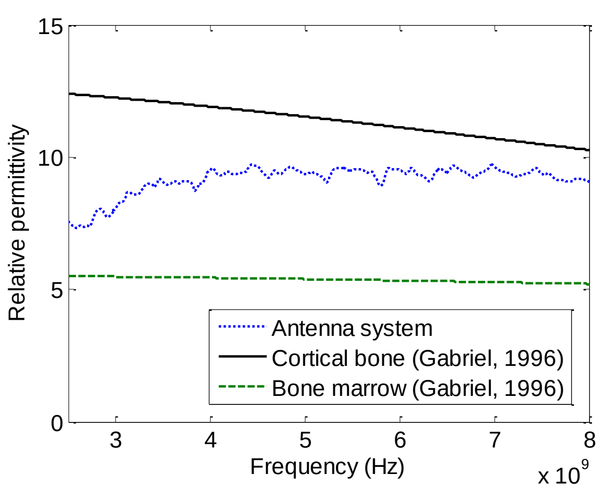

Figure 3. Estimated permittivity of an ex vivo porcine femoral bone excision (d = 30.20 mm) using the antenna transmission system, compared with results from [9] which used an open-ended coaxial probe

IV. Conclusion

A method of dielectric property estimation has been developed for biomedical applications. This technique will first be applied in the system described in [2], where the estimation of both permittivity and conductivity across multiple frequency presents an improvement to the existing time-of-flight estimation method. The 5x5 antenna array also allows for a low-resolution dielectric property image to be generated. Future work involves improved characterization of the radial spreading of the radiated signal. This is a complex phenomenon which depends on the properties of the tissue, the antenna separation distance, and the operating frequency. This technique will then be applied in other antenna designs with the objective of developing a wearable system capable of monitoring tissue dielectric properties.

V. Impact Statement

David Garrett was supported by the MTT-S Undergraduate/Pre-Graduate Scholarship, and he is very thankful for this opportunity to perform this research. He was encouraged by a supportive research group and colleagues to pursue graduate work, and is now working towards his M.Sc. in Electrical Engineering with Dr. Elise Fear. His research interests are focused on applying microwave techniques towards fitness and health monitoring applications. He is also chair of the University of Calgary MTT-S Student Branch, and is a co-founder of the campus Amateur Radio Club.

References

[1] M. S. Venkatesh and G. S. V. Raghavan, "An overview of dielectric properties measuring techniques," *Canadian biosystems engineering,* pp. 15-30, 2005.

[2] J. Bourqui and E. Fear, "System for bulk dielectric permittivity estimation of breast tissues at microwave frequencies," *IEEE Trans. Microw. Theory Tech.,* 2016 [Accepted].

[3] P. M. Meaney, D. Goodwin, A. Golnabi, M. Pallone, S. Geimer and K. D. Paulsen, "3D microwave bone imaging," in *European Conference on Antennas and Propagation*, Prague, 2011.

[4] J. Bourqui and E. C. Fear, "Shielded UWB sensor for biomedical applications," *IEEE Antenn. Wireless Propag. Lett.,* vol. 11, pp. 1614-1617, 2012.

[5] P. J. G. Bartley and S. B. Begley, "Improved free-space S-parameter calibration," in *Instrum. and Meas. Tech. Conf.*, Ottawa, 2005.

[6] W. B. Weir, "Automatic measurement of complex dielectric constant and permeability at microwave frequencies," *Proceedings of the IEEE*, vol. 62, no. 1, pp. 33-37, 1974.

[7] T. Henriksson, N. Joachimowicz, A. Joisel and C. Conessa, "Quantitative microwave breast phantom imaging using a planar 2.45 GHz system," in *General Assembly of the International Union of Radio Science*, Chicago, Illinois, 2008.

[8] D. C. Garrett, B. A. Besler, J. Bourqui and E. C. Fear, "Estimating bulk dielectric properties of biological tissues at microwave frequencies," in *Antenna Technology and Applied Electromagnetics (ANTEM), 2016 17th International Symposium on*, Montreal, Canada, 2016.

[9] C. Gabriel, "Compilation of the dielectric properties of body tissues at RF and microwave frequencies," Armstrong Laboratory, Brooks Air Force Base, Texas, 1996.