# Toward Non-Invasive Core Body Temperature Sensing

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***Abstract*— This paper aims to explore the potential of a novel radiometry technique that leverages bio-matched antennas (BMAs), broadband measurements, and forward modeling of layered tissues for non-invasive and accurate core temperature monitoring. Our approach relies on the observation that electromagnetic waves penetrate to different depths depending on their frequency and dielectric properties of the medium and adapts radiative transfer models that have been successfully implemented in the past for layered geophysical media. Preliminary modeling and experimental results confirm feasibility.**

## I. Introduction

Present-day standards of care for determining patient core body temperature are inhibited by a compromise between invasiveness and accuracy. Core body temperature is defined as "the temperature of the blood bathing the hypothalamus" [1]. Performing this measurement on a live patient is not feasible, so current means for accurate measurements require contact with the body's other highly perfused core organs. These methods include esophageal, nasopharynx, and pulmonary artery [1] thermometers. Though highly accurate, these measurements are only practical when the patient is placed under general anesthesia and can result in irritation at the applied site on waking. For localized anesthesia, the best options for temperature monitoring are at so-called "near-core" locations [2]. These sites include skin-surface, rectal, axillary, oral, and tympanic methods. However, these locations are located further from the defined core temperature, so factors such as environmental temperature affect the measured temperature. Thus, such measurements are not as accurate nor are able to detect temperature fluctuations as rapidly as the more invasive methods.

Identifying the need for non-invasive core body thermometry, companies such as 3M and Draeger have begun offering zero-heat-flux thermometers [3, 4]. These thermometers claim an accuracy of 0.5°C (the consensus for clinically acceptable accuracy [5]) but need approximately 10 minutes to achieve equilibrium, meaning they are not useful for extreme temperature fluctuations that can occur during cardiac surgery, for example [6]. Additionally, zero-heat-flux thermometers do not work at temperatures less than 32°C [7], which is well within the temperature range for life, namely 18°C to 46°C [8].

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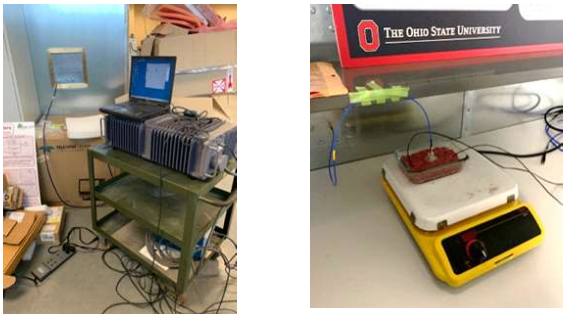
With knowledge of these shortcomings for core body temperature measurement, various groups have worked to apply microwave radiometry for non-invasive determination of body temperature. In [9], a five-band radiometer was designed to determine infant brain temperature using a rectangular waveguide antenna. The system had a resolution of about 0.1°C. However, the system error with a controlled phantom was 2.2°C, which is clinically unacceptable. Moreover, measurements required the use of a cumbersome water bolus placed between the antenna and the head phantom to facilitate matching. In [10], a radiometer was tested during a pediatric surgery with 1-2°C error throughout the experiment. However, 5 minutes of data was required for averaging, and thus this system was unable to detect rapid temperature changes. Additionally, these and other proposed on- and near-body radiometers utilize antennas with narrow bandwidths (less than 4:1), limiting measurement capabilities and making the system more susceptible to radio frequency interference (RFI) [1].

Having recently introduced a class of Bio-Matched Antennas (BMA) [12] designed to radiate into the body with bandwidth and gain greater than that reported previously in the literature, here we present preliminary models of radiometric brightness temperature. Together, the optimized antenna and models lay the foundation for an accurate and non-invasive method by which to determine core body temperature in real time, regardless of patient consciousness and body temperature.

## II. Ultrawide Band Radiometry for Medical Applications

The goal of this study is to demonstrate that ultra-wideband radiometry can be used for medical applications in order to retrieve core body temperature. Our approach relies on the observation that electromagnetic waves penetrate to different depths depending on their frequency and dielectric properties of the medium. Assuming an ultra-wideband radiometer, lower frequencies will penetrate deeper, while higher frequencies will be more sensitive to surface variations. Nevertheless, most medical radiometers reported to date operate at a single frequency [13, 14] (typically the quiet 1.4 GHz band that eliminates the "burden" of incorporating Radio-Frequency Interference, RFI, mitigation techniques). Some broadband medical radiometers have been reported [9] but they do not exceed bandwidths of 4:1 and rather target few frequencies in this range (5 in total). This implies poor resolution in targeting successive tissue depths, which deteriorates the accuracy of temperature retrieval. Further, frequencies reported for medical




(a) (b)

Fig. 1. Experimental setup: (a) wideband radiometer, and (b) hot plate used to head the phantom.

radiometry are in the high microwave range (>1 GHz), hampering sensing of deep tissue temperature. Here, we explore the feasibility of ultra-wideband frequency observations that exceed 4:1 bandwidths to boost temperature retrieval accuracy.

### A. *Modeling*

Previous studies on medical radiometry simulated the brightness temperature (i.e., the equivalent black body temperature) via Kirchhoff's law. The latter directly relates the emissivity (or brightness temperature) of the underlying medium to its physical temperature assuming that the medium's physical temperature is homogenous and constant. However, Kirchoff's law is not valid when thermal emission occurs by a layered medium with temperature variations across its layers and depth, such as the human body. Here, we advance thermal emission modeling by considering the layered aspect of tissues. That is, each layer (e.g., skin, fat, etc.) is characterized by its dielectric properties (permittivity, conductivity) and its physical temperature. This configuration enables more advanced radiative transfer implementations and more accurate modeling of thermal emission. To this end, radiative transfer models successfully implemented for layered geophysical media are adapted to simulate thermal emission of the layered body. Results will be presented at the conference.

### B. *Experiment*

As a proof-of-concept, a wideband radiometer that is available at The Ohio State University (originally developed for ground mine detections [15], Fig. 1(a)) is used. This radiometer includes 37 channels operating from 2 to 18 GHz. Our first experiment focused on calibrating the radiometer and testing the BMA. It was designed to be simple to model and interpret. Hence, a basic setup was employed that consisted of heating ground beef (commonly used to emulate the average human body properties [16]) on a hot plate (see Fig. 1(b)) and measuring the variations of the phantom's thermal emission as a function of temperature. To avoid RFI, the experiment took place inside a shielded chamber. Analysis of the acquired data confirms that the radiometer works as expected. Detailed results will be presented at the conference.

## III. Conclusion

We reported preliminary results for a novel medical radiometry technique that leverages bio-matched antennas (BMAs), broadband measurements, and forward modeling of layered tissues. Proof-of-concept modeling and experimental studies confirm feasibility for non-invasive and accurate core temperature monitoring. Building on such promising results, future studies will verify repeatability and expand to multi-layer phantom configurations. Detailed modeling and experimental results will be presented at the conference.

## References


[1] J. Robinson, R. Seal, D. Spady, and M. Joffres, "Comparison of esophageal, rectal, axillary, bladder, tympanic, and pulmonary artery temperatures in children," *Journ. of Ped.*, vol. 133, pp. 553-556, 1998.

[2] D. S. Moran and L. Mendal, "Core temperature measurement," *Sports Med.,* vol. 32, no. 14, pp. 879–885, 2002.

[3] *Introducing the 3M SpotOn Temperature Monitoring System.* 3M. https://multimedia.3m.com/mws/media/878163O/spoton-system-brochure.pdf

[4] *Tcore Temperature Monitoring System.* Draeger. https://www.draeger.com/Products/Content/tcore-br-9069837-en.pdf

[5] V.D. Hooper and J.O. Andrews, "Accuracy of non-invasive core temperature measurement in acutely ill adults: the state of the science," *Biological Research for Nursing*, vol. 8, pp. 24-34, 2006.

[6] J.A. Saster, M.J. Pascual, and T. Lopez, "Evaluation of the novel non-invasive zero-heat-flux Tcore thermometer in cardiac surgical patients," *Journ. of Clin. Mon. and Comp.*, vol. 33, pp. 165-172, 2019.

[7] M.T. Makinen et al., "Novel zero-heat-flux deep body temperature measurement in lower extremity vascular and cardiac surgery," *J.Cardiothorac. Vasc. Anesth.*, vol. 30, pp. 973-978, 2016.

[8] J. Sanko, "Thermoregulation: considerations for aging people," in *A Comprehensive Guide to Geriatric Rehabilitation*, 3rd ed., Churchill Livingstone, 2014, pp. 57–63.

[9] T. Sugiura, H. Hirata, J. W. Hand, J. M. J. Van Leeuwen, and S. Mizushina. "Five-ban microwave radiometer system for noninvasive brain temperature measurement in newborn babies: phantom experiment and confidence interval," *Radio Science,* vol. 46, pp. 1–7, 2011.

[10] P.R. Stauffer et al., "Non-invasive measurement of brain temperature with microwave radiometry: demonstration in a head phantom and clinical case*," The Neuroradiology Journal,* vol. 28, pp. 3-12, 2014.

[11] D.B. Rodrigues et al., "Design and optimization of an ultra wideband and compact microwave antenna for radiometric monitoring of brain temperature*," IEEE Transactions on Biomedical Engineering*, vol. 61, pp. 2154-2160, 2014.

[12] J. Blauert and A. Kiourti, "Theoretical Modeling and Design Guidelines for a New Class of Wearable Bio-Matched Antennas," *IEEE Transactions on Antennas and Propagation*, Early Access, 2019.

[13] K. Maruyma et al., "Feasibility of noninvasive measurement of deep brain temperature in newborn infants by multifrequency microwave radiometry," *IEEE Trans. Microw. Theory Tech.*, vol. 48, pp. 2141-2147, 2000.

[14] J.W. Hand et al., "Monitoring of deep brain temperature in infants using multi-frequency microwave radiometry and thermal modeling," *Physics in Medicine and Biology*, vol. 46, pp. 1885-1903, 2001.

[15] J. Johnson, H. Kim, D.R. Wiggins, and Y. Cheon, "Subsurface object sensing with a multifrequency microwave radiometer," *IEEE Trans. on Geosci. and Remote Sensing*, vol. 40, no. 12, pp. 2719-2726, 2002.

[16] C. Lee, A. Kiourti, J. Chae, and J.L. Volakis, "A high-sensitivity fully-passive neurosensing system for wireless brain signal monitoring," *IEEE Transactions on Microwave Theory and Techniques*, vol. 63, no. 6, pp. 2060-2068, 2015.