NEAR-FIELD THERMAL RADIATION RECEPTION SPATIAL SENSITIVITY MAPPING AT 1.4 GHZ

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INTRODUCTION:

Johns Hopkins lists "body temperature" at the top of their list of basic human vital signs [1]. However, measurement of internal tissue temperature is often limited to invasive techniques (needles and/or catheters [2]) or expensive and immobile clinical approaches (MRI [3] and zero heat flux [4]). In recent years, microwave radiometry has emerged as an alternative approach that is non-invasive, compact, low-power, and versatile [5].

Microwave radiometry operates by detecting electromagnetic radiation emitted naturally by the human body, with power approximated as $P=k_B T\Delta f$, where k_B is the Boltzmann constant [J/K], T the physical temperature [K], and Δf the observation bandwidth [Hz]. Radiation from multi-layered stacks is a weighted sum of contributions from each layer. Understanding layer properties (e.g., relative permittivity, ε_r, conductivity, σ [S/m], and thickness [mm]) is crucial, as is designing a near-field coupled receive element that exhibits increased power reception from the intended layer, minimizing reception from the lossy skin layers.

Numerous receive element topologies have been explored in the literature, including coupled slots [6], circular patches [7], planar folded dipoles [8], loaded bowties [9], loaded waveguides [10], and others. Vesnin *et al*. recently designed a wideband, planar receive element with an integrated infrared sensor for measuring skin temperature and receiving deep layer EM emissions simultaneously [11]. Validation of these designs has focused on aligning the simulated and measured return loss from the receive element ($|S_{11}|$). This work proposes, through reciprocity, a validation extension of the field distribution, and not just the reflection coefficient. That is, confirming that the simulated Joule loss density distribution, obtained by using the receive element as a transmitter, matches the simulated sensitivity distribution when the receiving element is receiving thermal noise.

MATERIALS & METHODS:

The near field receiving element used for this work was published in [12]. It is a corner-fed rectangular patch, analogous to an antenna but designed for placement directly on a lossy tissue or a tissue phantom. A high tangential component of the electric field is desirable at the interface, as that is continuous across boundaries of dielectric layers. A rectangular patch satisfies this requirement and is easily manufactured. The element is designed to operate in the 1.4-1.427 GHz band designated as a quiet band for radio astronomy, thus the propensity for electromagnetic interference is reduced.

The volume density of Joule losses for the receiving element against a polypropylene reservoir (ε_r = 2.2 and σ = 1 [μS/m] [13]) of phosphate-buffered saline (PBS; ε_r = 77.7 and σ = 1.26 [S/m] [14]) is simulated in HFSS. A cut-plane is added through the center of the patch, parallel to its short axis, and the resulting slice of the complex electric field magnitude (|**E**|; dB([V/m])) as well as the joule loss distribution [W/m^3], are shown in Fig. 1. The volume density of Joule losses, through reciprocity, is a mapping of the sensitivity of thermal noise emissions from the saline. To validate this distribution, a polypropylene tube containing PBS is inserted into the reservoir. The temperature of the PBS in the tube differs from that in the reservoir. It is expected that when the tube is in a region where the Joule losses are high (immediately above the receive element), a relatively large shift in output (proportional to the temperature difference between the tube and the reservoir) is measured.

RESULTS:

Simulations indicate that tube wall thickness and insertion depth impact the near-field Joule losses and the impedance match of the receive element. As shown in Fig. 2, match improves as the insertion depth of a thick-walled (2mm) tube is reduced. However, this also reduces the coupling into the saline within the tube by up to about 43.5% as the tube is raised to 5mm from the bottom of the reservoir. Preliminary measurements suggest that thin-walled, small diameter tubes (~5mm) do not create a disturbance sufficient to be measured. This necessitates the use of larger tubes, which in turn create impedance mismatch issues that will need to be accounted for.

DISCUSSION:

On-going testing toward empirical validation of reciprocity in the near field requires careful attention to experiment design. Alternative methods for introducing disturbances might need to be utilized. Additionally, both the thermal and microwave impacts of introducing a disturbance need to be considered.

SIGNIFICANCE:

This work presents progress toward expanding design validation of near field receive elements for microwave radiometry (often limited to aligning $|S_{11}|$ in simulation and measurement) to include empirical validation of the near field coupled sensitivity. References to this type of validation have not yet been found in the literature.

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DISCLOSURES:

All authors have nothing to declare. No human or animal subjects were used in this research project.

FIGURES AND TABLES:

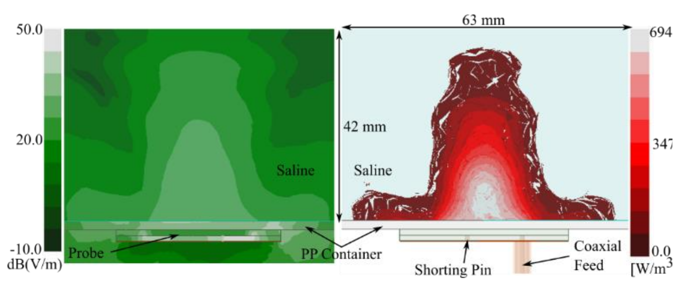

Figure 1: Simulated electric field magnitude (left) and joule loss density (right) of a transmitting near-field element against a reservoir of saline. Via reciprocity, the joule losses are a sensitivity mapping for a receiving near-field element.

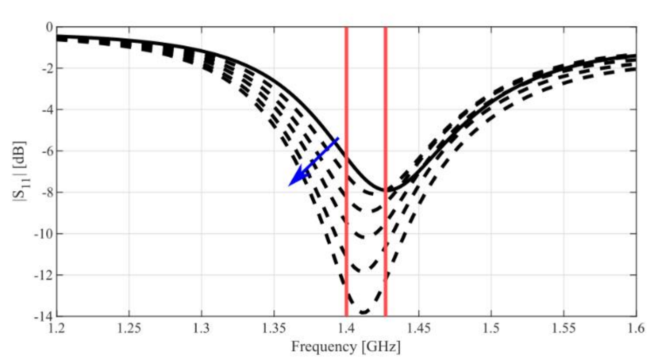

Figure 2: Simulated return loss as thick-walled tube insertion depth is swept from 0 to 5mm. The operational band is indicated by the red vertical lines.