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Near-Field Antenna for Noninvasive Human Head Microwave Thermometry

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***Abstract*—Microwave radiometry is an emerging technology for noninvasive measurement of internal body temperature. This technique relies on the use of a near-field antenna placed on the skin that receives black body radiation from the tissues under it. Even for a well-matched antenna, mismatch is introduced from variations in the tissue layer properties and/or imperfect characterization of the dielectrics used for antenna assembly. This work demonstrates a design of a receiving antenna element for a human head-specific tissue stack, and a tuning procedure to improve impedance match. Measurements of a fabricated antenna against the forehead indicate that inaccurate characterization of the materials used for antenna assembly more significantly contribute to antenna mismatch than variations in the tissue properties of the forehead. Therefore, proper modeling of assembly materials, in addition to reasonably accurate tissue stack modeling, is crucial for near-field antenna design.**

I. Introduction

There are a host of medical disorders which originate from temperature regulation dysfunctions including hyperthermia, circadian rhythm disruptions, and hypoxia ischemia [1]. Although millions of people are affected by these disorders, continuous, noninvasive temperature monitoring of internal body tissues, including organs such as the heart and brain, is either invasive (e.g. catheters), impractically costly and large (e.g. MRI) or inaccurate (e.g. zero heat flux sensors). An emerging innovation for internal thermometry is microwave radiometry [1], [2]. This technique is based on the principle that tissues radiate electromagnetic energy across the electromagnetic spectrum, described by the black-body radiation law, with a peak at a frequency that depends on temperature. For a human body, the peak radiation is in the infrared (IR) region, however waves in the IR have a penetration depth in tissues that is on the order of a millimeter. To measure thermal power radiated from deeper tissues, lower microwave frequencies can be used.

A near-field antenna placed on the skin will receive the total power spectral density from all tissues under it. To be used effectively with a radiometer, the antenna should be designed with a near field radiation pattern that maximizes reception from the desired tissue layer. The total received power depends on the bandwidth of the receiver, B and the temperatures of all the layers under the antenna: $P = kB \cdot \Sigma w_i T_i$, where k is the Boltzmann constant, and w_i, T_i are the weighting factors and temperatures of the layers [1]. This work shows the design of a narrow-band (1.4-1.427 GHz, quiet band) near-field patch antenna, designed for the human forehead, as shown in Fig. 1, with tissue properties given in Table I. For the 27 MHz bandwidth, the received power is on the order of -99 dBm, thus a well-matched receiving antenna is crucial. Previous works have explored the use of various planar topologies [1], slots, and waveguides [3]. Because the antenna is receiving power from the near field, its performance is susceptible to variations in the thicknesses and dielectric properties (relative permittivity, ϵ_r and conductivity, σ) of the tissue layers. This impacts the resolution of the radiometric temperature measurement and is important to quantify. In this paper, a comparison of full-wave simulations to measurements for the human forehead is presented to characterize this variation.

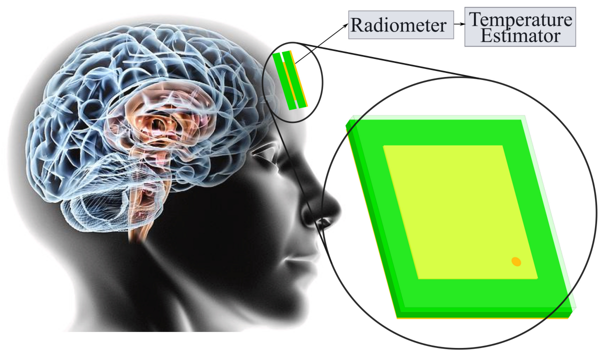

Fig. 1: Block diagram showing a near-field patch antenna matched to the forehead, designed to receive power for brain temperature microwave thermometry.

TABLE I: Properties of forehead tissue stack at 1.4135 GHz.

Tissue	Thickness (mm)	ϵ_r	σ (S/m)
Skin	2	39.6	1.04
Fat	2	5.39	0.065
Muscle	4	54.1	1.15
Skull	7	19.9	0.47
Cerebrospinal fluid (CSF)	3	67.7	2.67
Brain	90	44.2	1.50

II. Near-Field Patch Design

The narrowband near-field thermometry antenna is a corner-fed rectangular patch positioned between a substrate and superstrate, using 1.27 mm thick Rogers 3010 dielectric. The antenna is matched to a six-layer tissue stack emulating a human head and exhibits significant reception from the cerebrospinal fluid, which is at a similar temperature as the brain (Table I). The layer thicknesses for full-wave HFSS simulations are chosen from maximum thicknesses near the forehead region provided in [4], while the electrical tissue parameters are modeled using Debye dispersion models in HFSS from 0.1 to 3 GHz, with dispersion data from [5]. The resulting design is shown in Fig. 2, where the superstrate is

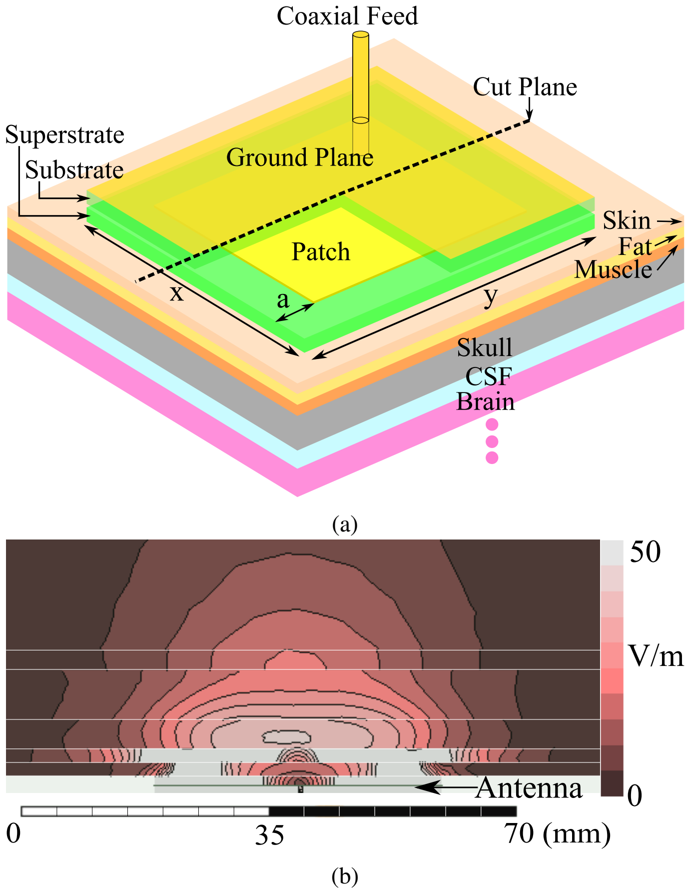

Fig. 2: (a) Rectangular patch with superstrate, on a subset of the six-layer human head tissue stack from Table I. $(x, y) = (36.7, 40.85)$ mm are obtained with manufacturer-provided substrate properties. The spacing between substrate edge and patch is 12.7 mm. (b) Simulated electric field magnitude in the tissues at 1.415 GHz, along the cut plane shown in (a).

needed to improve antenna matching to the skin. The initial dimensions $(x, y) = (36.7, 40.85)$ mm use manufacturer-provided dielectric properties for the superstrate and substrate, ϵ_r=11.2, $\tan\delta = 0.0022$.

III. Measured Results, Matching Improvements and Conclusions

The initial design is fabricated and its impedance measured on different locations on a human forehead. This was repeated on two people and similar performance observed in both cases. Observed shifts in desired frequency response are compensated by a redesign $(x, y) = (36.7, 41.85)$ mm. Simulated and measured $|S_{11}|$ for the two designs are given in Fig. 3, showing that the redesigned prototype has improved match and is less sensitive to positioning. The dashed lines in the plots show simulated results against the tissue stack of Table I before and after retuning the dimensions of the patch.

In conclusion, this paper presents a near-field patch antenna placed on the forehead for microwave thermometry of the brain. A comparison of the simulated and measured results show an upwards shift in the resonant frequency which can be accounted for by shifts in the ϵ_r of the antenna dielectric substrate and superstrate. Once the dimensions of the patch are retuned to account for this variation, the antenna shows good performance in the desired frequency range regardless of placement on the forehead.

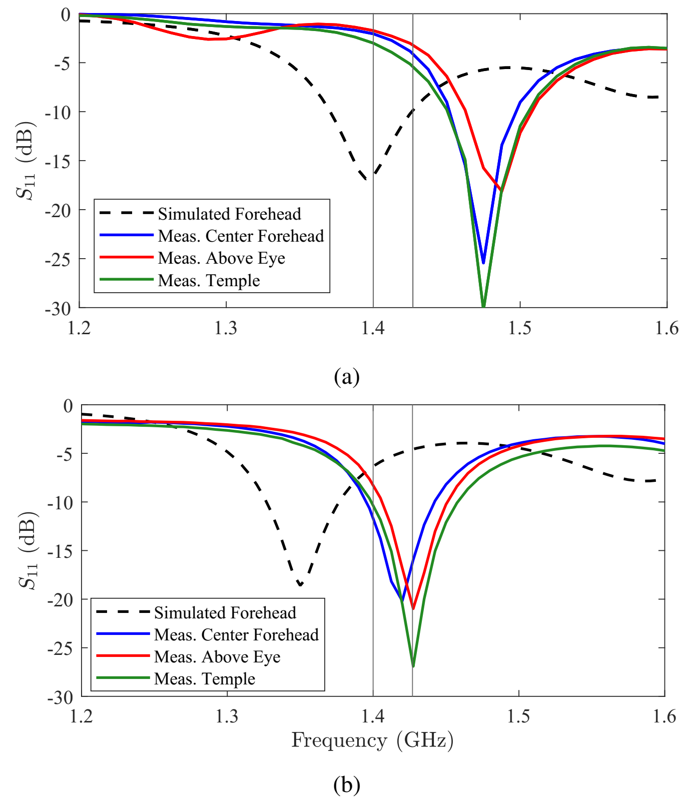

Fig. 3: Simulated and measured $|S_{11}|$ of the antenna assembly against the forehead (a) with initial design and (b) with a retuned design to correct for inaccuracies in the design model.

Acknowledgement

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