Broadband Probe for Subcutaneous, Noninvasive Thermometry

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Accurate, continuous temperature measurements of internal human organs such as the heart and brain are important for quickly diagnosing and treating a number of medical conditions such as circadian rhythm disfunctions, hyper- and hypo-thermia, and hypoxia ischemia. Invasive methods such as rectal or oral thermometers, or expensive methods such as MRI, are not feasible for continuous temperature monitoring. Previous work has proposed the use of microwave thermometry to noninvasively and passively measure internal temperatures (e.g., P. Momenroodaki et al., IEEE Trans. on Microwave Theory and Techniques, pp. 2535-2545, Dec. 2017 and M. K. Sedankin et al., APEDE, 24-25, Sept. 2020). In these prior works, a radiometer is connected to a near-field probe antenna which receives thermal radiation from the body. This thermal radiation is proportional to a weighted sum of the physical temperatures of tissue layers directly under the probe.

Several probe topologies have been explored in the literature, including microstrip patches, planar folded dipoles, coupled slots, and dielectrically loaded waveguides. In general, these narrowband designs are sensitive to impedance mismatch due to variations in the dielectric properties and thicknesses of the tissue layers. Such variations appear not only between different measurement sites on the same patient but also between the same measurement sites on different patients.

In this work, we explore the use of a broadband planar probe that is more resilient to variations in tissue characteristics and feasible for use at a variety of locations on the body. Additionally, a broadband probe can receive power at multiple narrow frequency bands, which can improve spatial sensing resolution. We demonstrate that the designed probe is feasible for use against a number of tissue sites through two metrics. First, return loss is used to evaluate matching against the tissue stacks. Second, by leveraging reciprocity, the volume density of Joule losses (VLD) is used to evaluate sensing depth. In simulation, the probe achieves a good return loss for both a 6-layer tissue phantom mimicking the forehead and a 3-layer soft tissue phantom from about 1 to 3 GHz, showing good tolerance to placement on the body. The VLD shows sensing depth between 1.5 and 3 cm for the two cases over the 1 to 3 GHz band.