Accurate Absolute Thermal Monitoring With RF Radiometry

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Introduction

Measuring and monitoring RF power deposition and heating is of critical importance to the safe operation of MRI scanners. With the ever-increasing field strength of scanners used for human studies, the need for noninvasive and independent tools that can measure body temperature beyond skin-depth is all the more urgent. An MRI scanner can be used as a radiometer to passively measure the RF noise power emitted by the human body between excitations, and to perform absolute thermal measurements [1-3]. The idea of MRI radiometry is based on the well-established theory of black body radiation. The equation governing this phenomenon in the microwave region for a typical receiver chain is $P= 4G(\Gamma(T))kBT+N(\Gamma(T))$. Where P is the radiated noise power, G is the power gain of the receiver, Γ is the reflection coefficient at the coil/receiver interface, k is the Boltzman constant, T is the temperature of the body, B is the system's bandwidth, and N is the noise power added by the receiver. In lumped form, this relation can be written, $P= \alpha(\Gamma)T+\beta(\Gamma)$, where α and β are unknown lumped system parameters. When Γ is constant, the system parameters are stable and α, and β can be characterized by calibration of the noise power using known temperature loads. After calibration, temperatures can be directly estimated from the noise variance. Here we present a new impedance sensing system for RF radiometry that has an accuracy of 0.1Ω which allows for continuous impedance sensing, matching and calibration with a temperature accuracy of 0.2^{0}C. The system is validated with phantom studies over physiological temperature ranges of 28-40 ^{0}C.

Methods

The idea for impedance sensing is based on connecting a sense coil to a Maxwell bridge whose output is fed to a quadrature mixer (Fig 1). Before each measurement the impedance sensing circuit is calibrated using 3 precision impedance reference loads. The coil impedance is then measured with an accuracy of 0.1Ω and electronically matched using a π network. After the coil is matched it is connected to an amplification stage for noise power measurements. A block diagram of the automated system is shown in (Fig. 2).

Experiments

The radiometric system was tested with heated water phantoms containing various concentrations of saline. Phantom temperature was accurately controlled and monitored via an independent fiber-optic temperature sensing device connected to a heater. The radiometer was first calibrated against references of known temperature. After calibration, radiometric temperature measurements were performed and compared with the independent sensor measurements (Fig. 3). The calculated root-of-the-sum-of-the-square error over four studies shows an accuracy of 0.2^{0}C in temperature estimation.

Discussion

We have demonstrated with phantom studies that RF radiometry, in the form of continuous RF impedance sensing with careful matching and calibration, can be used to detect absolute temperature with an accuracy of 0.2^{0}C over a physiological range. Based on our previous studies in the MRI scanner [1, 3], we anticipate that integration of such systems into scanners could prove useful as independent monitors of power deposition and temperature during MRI scans.

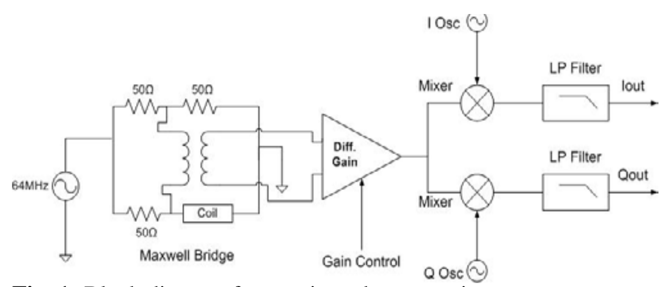

Fig. 1: Block diagram for true impedance sensing.

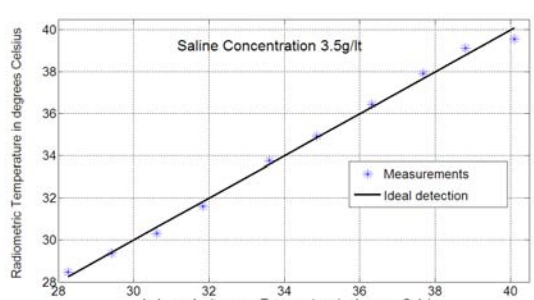

Fig. 3: Temperature measured from noise power vs temperatures measured with fiber optic probes.

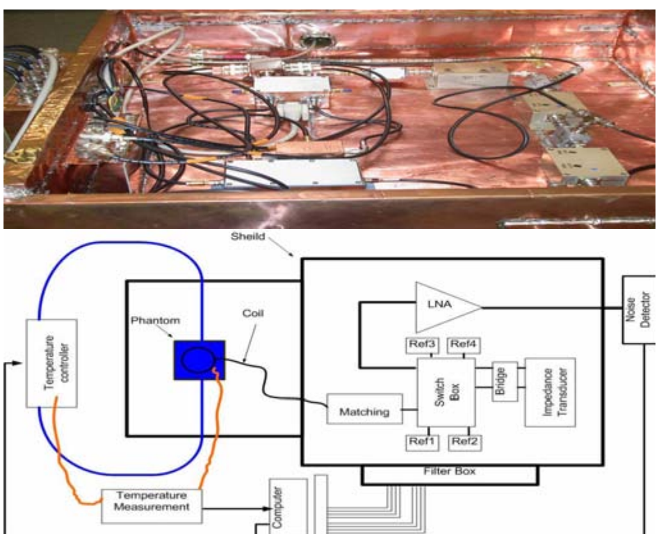

Fig. 2: Photo of the system electronics (top). Block diagram of the system used for impedance sensing, matching, calibration and noise measurement with the experimental setup for phantom testing .and temperature monitoring.

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References:

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