Monitoring local heating around an interventional MRI probe with RF radiometry

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Audience. MR scientists and engineers interested in interventional MRI, thermal and RF safety.

Purpose. To monitor the temperature changes associated with an active interventional MRI loopless antenna detector, independent of MRI, to ensure safe operation and/or allow local monitoring of thermal therapy delivery.

Theory. The electromagnetic (EM) radiation from a lossy material is proportional to its absolute temperature permitting temperature estimation via radiometry, based on the noise voltage, S_{meas} measured in a certain frequency band [1]. The mean-squared noise is proportional to the average of the temperature distribution in the medium weighted by the local specific absorption rate (SAR) of the antenna that detects the signal: $S_{meas} \sim \int_V T(r)\cdot\sigma(r,T)\cdot|E(r)|^2 dr$; where r is a spatial variable, σ is the electrical conductivity and E is the electric field distribution [2].

Methods. Experiments were conducted in a loose gel phantom having bio-analogous electrical properties [3], with a semi-rigid 128MHz quarter wavelength loopless antenna inserted. Local temperature was monitored at 1Hz using fiber-optic temperature sensors (Neoptix, Inc., Quebec, Canada) placed in close proximity to the antenna. The loopless antenna was connected to a 128MHz super-heterodyne radiometry receiver with a 410kHz bandwidth. The baseband signal centered at 3.2MHz was sampled at $2\text{x}10^6$/s, and the mean-squared voltage determined in 0.5s intervals. The gel was uniformly heated to 25-77°C and its temperature sampled by the sensor at the cable-whip junction at 1Hz, to calibrate the radiometer. RF power was then applied to the loopless antenna to induce local heating, radiometric and local temperature measured. The SAR distribution was computed numerically using FEKO EM software (Stellenbosch, South Africa). The spatial distribution of the temperature rise was characterized using MR thermometry (T1w-GRE, TR/TE = 50/20, voxel size: $1.5\text{x}1.5\text{x}2\text{mm}^3$, duration: 5.4s), and thermal sensors.

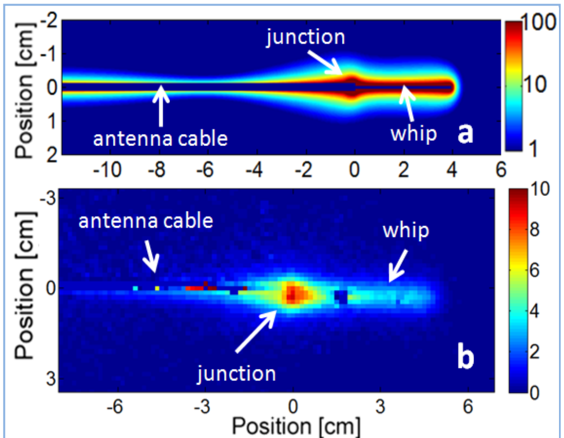

Fig. 1. (a) SAR distribution of the loopless antenna. **(b)** MR thermometry following 30s 5W RF exposure.

Results. The SAR (Fig. 1a) and the measured spatial temperature distributions (Fig. 1b) are highly localized around the cable-whip junction of the loopless antenna. The radiometer tracked the homogenous temperature changes with an accuracy of ±0.24°C. Local heating induced by applying RF power to the antenna also tracked sensor measurements up to ~80° (Fig. 2). The figure shows that the radiometer is primarily sensitive to the peak local temperature around the cable-whip junction, with small differences attributable to sensor positioning.

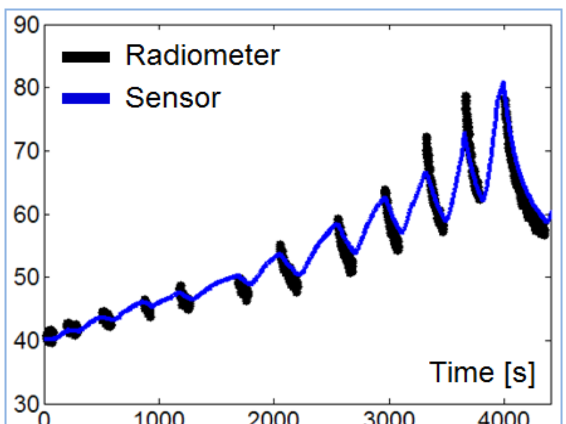

Fig. 2: Radiometric and thermal sensor (cable-whip junction) temperature during local RF heating.

Conclusion. Temperature in the vicinity of an active internal loopless antenna can be determined within 0.3°C by RF radiometry at the 3T MRI frequency. As the radiometry receiver is equivalent to an MRI receiver [2], the scanner itself may be used for radiometric measurements to monitor heating, by interleaving the radiometric voltage measurements between the applied MRI scan sequence.

References. 1. Pozar DM. Microwave Engineering, 3ed. (John Wiley & Sons, Inc., New York, 2005). **2.** El-Sharkawy AM et al. IEEE Trans Circuits Syst I Regul Pap 53, 2396-2404 (2006). **3.** Erturk MA et al. Magn Reson Med. 68(3): 980-8 (2012).

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