PhD Thesis title: 'Enabling Interventional MRI Using an Ultra-High Field Loopless Antenna'

Author: Mehmet Arcan Ertürk
Email: arcanerturk@gmail.com
Institution: Johns Hopkins University, Dept of Electrical & Computer Engineering
Supervisors: Paul A. Bottomley, PhD
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Available on line: n/a

ABSTRACT:

Interventional Magnetic Resonance Imaging (iMRI) utilizes multi-functional capabilities of MRI, for targeting therapy and monitoring response. Up to recently, most of the iMRI procedures have been conducted at magnetic field strengths (B_0) of 1.5 T or lower. MRI at ultra-high field (UHF, $B_0 \geq 3T$) provides higher signal-to-noise ratio (SNR) that can be traded for better image resolution and/or shorter scan durations. This dissertation investigates the performance of the interventional loopless antenna at UHF and introduces new methods to enable UHF iMRI using interventional loopless antennae.

First, a new MRI denoising method based on a spectral subtraction technique that can provide up to 45% of SNR improvement is introduced. While achievable SNR gains using post-processing methods are limited, the SNR of MRI is intrinsically improved by moving to higher B_0. Here, the performance of a loopless antenna was tested at 7 T. The results show that SNR increases quadratically with B_0 ($SNR \sim B_0^2$) up to 7 T. The increased SNR of the loopless antenna at UHF enables MRI at sub-50 µm in-plane resolutions.

At UHF, excitation of tissue deep within the body becomes challenging due to the decreased penetration depth, and radiofrequency (RF) safety limitations when external coils are used. To overcome these problems, we used the loopless antenna for both transmitting the RF field, and receiving the MR signal from the tissue. Spatially selective B_1-insensitive pulses were employed to improve the excitation homogeneity, providing a ~10 cm FOV, which would be suitable for both device-tracking and localizing potential targets inside the body.

Use of interventional devices in transmit and/or receive mode may elevate temperatures near the device above levels considered safe. To address this problem, we built a loopless antenna RF radiometer operating at 3 T MRI frequency, 128 MHz, to monitor the local temperature around the device. We investigated its performance inside bio-analogous phantoms and using electromagnetic and thermal numerical simulations. The radiometer was able to detect uniform temperature with an accuracy <0.3 °C at 2 measurements/second, and estimate the peak 1 g-averaged temperature rise within 0.4 °C. The loopless antenna radiometer can be used to ensure safety of interventional procedures, without requiring any additional leads or sensors, or even MRI.

References to author publications that relate specifically to the dissertation:

1. M. Arcan Erturk, AbdEl-Monem M. El-Sharkawy, Paul A. Bottomley. *"Interventional loopless antenna at 7 T"*. Magnetic Resonance in Medicine, Volume 68, Issue 3, pages 980-988, Sep 2012.

2. M. Arcan Erturk, Paul A. Bottomley, AbdEl-Monem M. El-Sharkawy. *"Denoising MRI Using Spectral Subtraction"*. IEEE Transactions on Biomedical Engineering, Volume 60, No. 6, pages 1556-1562, June 2013.

3. M. Arcan Erturk, AbdEl-Monem M. El-Sharkawy, Jay Moore, Paul A. Bottomley. *"7 Tesla MRI with a Transmit/Receive Loopless Antenna and B_1-Insensitive Selective Excitation"*. Magnetic Resonance in Medicine, published online: August 20, 2013.

4. M. Arcan Erturk, AbdEl-Monem M. El-Sharkawy, Paul A. Bottomley. *"Monitoring Local Heating Around an Interventional MRI Antenna with RF Radiometry"*. Medical Physics, (under review).