RF Ablation Electrode Current Imaging by MRI

G. C. Scott[1], A. Chen[1], K. Vigen[2], S. Conolly[1]

[1]Electrical Engineering, Stanford University, Stanford, California, United States, [2]Stanford University, Stanford, California, United States

Introduction: RF ablation is a clinically proven procedure for minimally invasive therapies ranging from cardiovascular electrophysiology to cancer tumor ablation. MRI appears to be well suited to provide interventional thermal monitoring for these procedures[1]. Since RF ablations use frequencies below 1 MHz, the possibility exists to also image the RF ablation current by prepolarized MRI. With our PMRI scanner [2], we recently demonstrated our first high SNR MRI images of RF current at 1.1 MHz. However, clinical scanners use fields with Larmor frequencies well above ablation frequencies. If ablation could be performed at the higher Larmor frequencies, then direct monitoring of the ablation pathways becomes possible. Here, we first show that an RF ablation current from clinical ablation electrodes can be imaged by PMRI. We then show the hardware developments necessary to implement this technique on a 0.5T GE SP scanner with the goal of correlating 1 MHz and 21 MHz RF ablation current pathways.

Methods: On our PMRI scanner, we tested the achievable tissue contrast and current pathways for an RF ablation electrode. We used a Boston Scientific MRI compatible Leveen electrode in a pork sample which had layered muscle and fat (Fig. 1). We prepolarized to 0.35T for 350ms, and then applied a 12 ms RF current at 1.1 MHz in a readout field of 0.026T. To perform current density imaging, we had constructed a second RF transmitter channel to supply RF current at the Larmor frequency but with 0, 90, 180 and 270 degree phase shifts[3]. Current was injected synchronously while the MRI scanner played out a rotary echo hard pulse. The rotary echo fully refocused hard pulse flip angles leaving a net rotation due only to the superimposed RF magnetic fields from current. This rotating frame angle was converted into a phase image by a 90 degree plane rotation. Phase images were post-processed by differential curl operations to compute current density[4].

To perform the experiment on a 0.5T scanner, we constructed a new quadrature phase shift system tuned for 21.3 MHz (Fig 2). This circuit only requires a 2 stage polyphase filter with the $1/2\pi RC$ products set for 21.3+\- 1 MHz. The small signal RF input is taken from the sampled RF output channel of the GE Signal system. A pulse sequence logic control triggered the gating of this second channel which was then fed to a AR Kalmus 200 W amplifier.

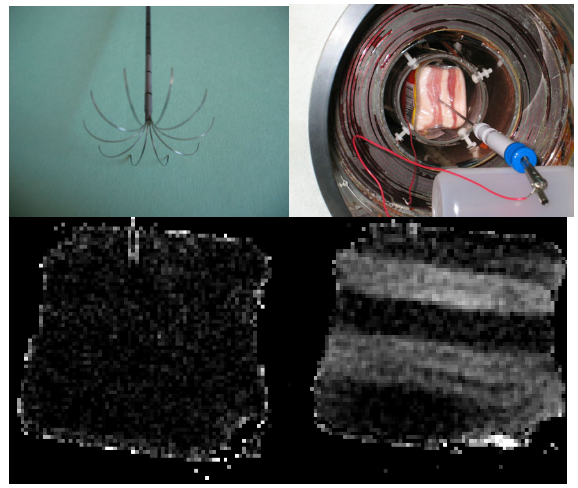

Figure 1: PMRI 1.1 MHz current density image of a pork sample using a Leveen RF ablation electrode. Current is off in bottom left and on in the bottom right.

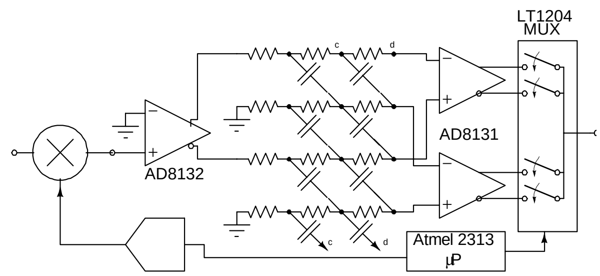

Figure 2: 21.3MHz RF polyphase transmit channel.

Results: The PMRI current images are shown in Figure 1 with RF current off and then on. We clearly delineate muscle layers which had high tissue conductivity at 1.1 MHz while fat acted primarily as an insulator. When current was off, the image shows only noise as expected.

For our first tests on the 0.5 T system, we first characterized the phase shift transmitter system (Fig 3). We had less than 0.3 degrees quadrature error and under 0.5 % gain error for our 4 channels at 21.3 MHz. This is more than adequate for current imaging. Our first RF field map phase images are shown in Figure 4 for a 5.7 cm phantom with current injected by electrodes through saline in a center tube. The patterns are virtually identical to our earlier 1.1MHz tests. On the left, the phase image that encodes the rotating frame Hx field is presented, and on the right, the Hy phase map is shown. The linear phase ramps in the center tube are indicative of uniform current inside this tube.

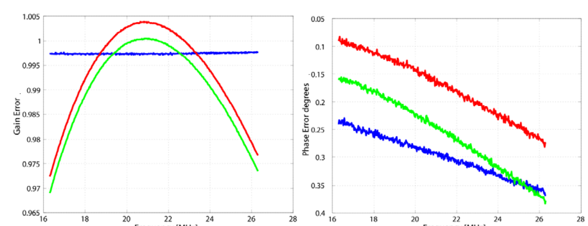

Figure 3: The 0.5T gain and phase accuracy of the 90, 180 and 270 degree channels relative to the 0 degree channel.

Discussion & Conclusions: Our tests clearly show that conductivity contrast is present in the tissue tests since fat blocks the ablation currents. In more heterogeneous tissue such as the breast, RF ablation current pathways will be quite irregular. In future, we want to determine how different these pathways are for 21.3 MHz and 1 MHz or lower. If similar, then 21.3 MHz current images will be a good predictor of RF ablation currents at the lower frequencies.

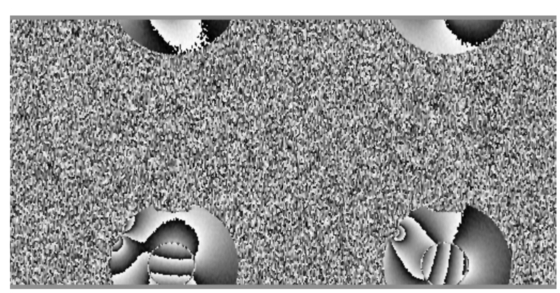

Figure 4: Raw phase maps that encode the rotating frame Hx and Hy fields on the Signa SP 0.5T system. These are the classic field patterns created by a uniform 21.3 MHz RF current in the center tube.

References:

[1] K. Vigen et al, Proc 11th ISMRM, p 685, 2003
[2] S. Conolly et al, Proc. 9th ISMRM, p 683, 2001
[3] G. Scott et al, Proc 11th ISMRM, p710, 2003.
[4] G. Scott et al, Magn. Reson. Med. 33:355-369, 1995

The authors would like to acknowledge the support of the Whitaker Foundation.