A Method Based on Infrared Techniques for Experimentally Verifying RF Coil Full-Wave Modeling

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Introduction: The uniformity of the MRI excite (B_1^+) and receive (B_1^-) RF fields greatly influences image quality. Although computational electromagnetics can be used to predict these fields, experimental measurements of the RF fields are still necessary for validating the computational predictions and for confirming the performance of the RF coils. In this work, we 1) outline a technique for using infrared (IR) imaging [1,2] to experimentally verify full-wave modeling of RF coils and 2) present experimentally verified finite difference time domain (FDTD) calculations of ultra high field loaded RF coils.

Methods:

Infrared Technique: The procedure used to perform IR measurements of RF coils' associated electromagnetic fields is as follows. First, a thin resistive sheet is adhered to a non-conducting electromagnetically transparent backing (Styrofoam). The properties of these sheets are as follows: thickness δ = 60 microns, surface resistivity = 1150 Ohms per square, heat capacity $C = 1.4 \times 10^6$ J m^{-3} K^{-1}, convection coefficient $h \approx 2$ [W m^{-2} K^{-1}], thermal diffusivity $K = 10^{-7}$ m^2/s (resulting in slow blurring), and relaxation time constant = 30^{-1} S^{-1} (resulting in fast cooling). The sheet and backing material are then placed in the coil at the location of interest. For these studies, we have chosen 2 TEM resonators which are comprised of 16 and 24 coaxial lines with eccentrically placed center conductors. The coils are then tuned such that their standard mode of operation (second mode on the spectrum) is resonant at 340 MHz. In our studies, we have tested the 24-strut coil while empty and the 6-strut coil while loaded with a spherical phantom (18.5 cm in diameter) filled with 0.125 M NaCl for appropriate loading (ε_r = 78 and conductivity = 1.154 S/*m*). To avoid contamination of the measured IR image by extraneous thermal radiation from ambient light and emission from nearby warm objects (e.g., human operators), measurements are conducted in a light-excluding chamber. The IR camera is then used to observe the sheet prior to application of the RF power, thus providing an estimate for initial radiation. Next, a modest level of RF power (average power 1 W) is applied for a few seconds, and a second IR image is acquired. The difference image yields the electromagnetic behavior of the coil.

FDTD Calculations: FDTD models of both the 16-strut and 24-strut TEM resonator were created. The model dimensions were the same as those utilized in experiment. A dielectric constant of 2.2 was used between the inner and the outer rods to resemble the Teflon tubes utilized in the actual coils. The spatial step was set to 2 mm. A stair-step approximation was used to model the shield and the top and bottom rings of the coil while a modified FDTD algorithm was utilized to model the curvatures of the inner and outer struts. The calculated electric and magnetic fields were then obtained by numerically 1) tuning each coil by adjusting the gap between the TEM stubs until the TEM resonator's mode of interest was resonant at the desired frequency of operation, and 2) exciting the port of interest without forcing current distribution on any of the coil struts.

Results and Conclusions: The IR images obtained prior to and after applying the RF field, the median filtered images, and the FDTD calculated distribution of E-field^2 are shown in Figure 1 for a loaded 16-strut coil and an empty 24-strut coil. Median filtered images are the subtracted images after applying medial filtering to avoid spikes in regions of no interest. In this figure, the coils were excited linearly in the bottom left strut and were tuned to 340 MHz. The resistive sheet was positioned near the excitation location where the coil feeding was done and in front of the camera lens. The outline of the coil is apparent in these images because the copper surfaces were slightly cooler than the ambient air. The results show very good agreement between the FDTD and the IR results. Note that the numerical data were shifted azimuthally such that the excited port matches that utilized in the IR measurement. In the empty coil, throughout the central bulk of the slice shown in Figure 2, the difference between the FDTD and IR measurements was less than 4%; only near the edges of the coil's end ring, this number rises to some random values, which is expected because of the relatively significant difference in the temperature between the coil copper surface and the resistive sheet. The data clearly show the effect of loading, where the coupling between the lossy head-sized load (0.125 M NaCl filled sphere of diameter 18.5 cm) and the excitation port is significant at 340 MHz. While the excited port does not have much of an affect in the air (empty coil), the maximum electric field values are located near the source location. As a result of the inhomogeneous electric field distribution at the coil's aperture, radiation occurs non-uniformly (across aperture) as well. With these measured IR values, one can readily and accurately obtain the coil's radiation losses as opposed to using a sniffing coil which 1) can cause perturbation in the coil's electromagnetic fields and 2) must be placed at many areas across the coil's aperture to accommodate for the field inhomogeneities.

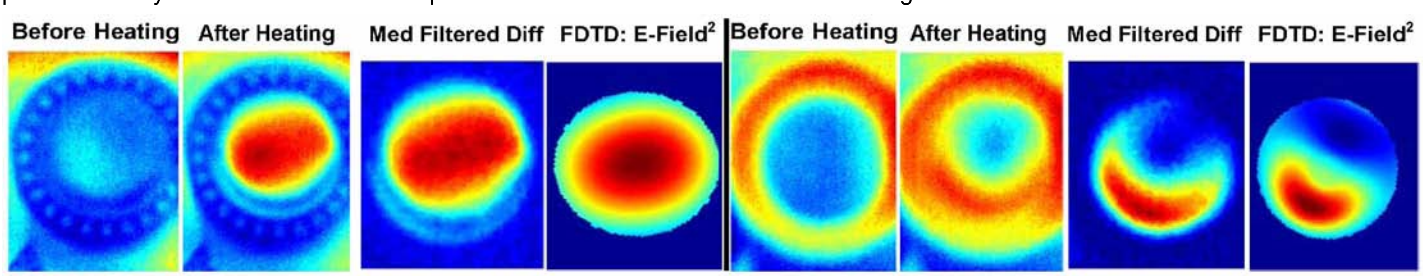

Figure 2: Infrared images and FDTD calculated transverse E-Field^2 distribution of axial slices through an empty 24-strut (left set) and a 16-strut loaded with a spherical phantom filled with 0.125 M NaCl (right set) TEM resonators. The coils were linearly excited and tuned to 340 MHz.

References:

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