An accurate electromagnetic field model for optimization and selection of intravascular multimode coil geometry

Madhav Venkateswaran[1], Samuel A. Hurley[2], Alexey Samsanov[2], Peng Wang[2], Orhan Unal[2], and Krishna N. Kurpad[3]

[1]Electrical and Computer Engineering, University of Wisconsin, Madison, WI, United States, [2]Medical Physics, University of Wisconsin, Madison, WI, United States, [3]Radiology, University of Wisconsin, Madison, WI, United States

Target Audience: Interventional radiologists and cardiologists, MRI coil designers.

Purpose: To develop a simulation methodology to accurately model intravascular coils under actual scanning conditions and to compare their performance through simulation.

Methods: The multi-mode coil consists of a series-tuned imaging coil and tracking coil in series [1] and is designed to couple inductively to the transmit coil during transmit phase. The signal profile of the coil can therefore be optimized for the specific functionality by adjusting the B_1 field profile [2]. The functional requirements for tracking and imaging coils are divergent, with the latter requiring broader radial and axial coverage and the former requiring a highly sensitive and localized signal, such that it yields a dominant sharp peak for accurate tip-tracking. The tracking and imaging coil geometry can be optimized for improved multimode coil performance. Numerical simulation is a good option to perform this optimization and requires an accurate estimate of the current induced in the multi-mode coil by a circular polarized B_1 field. In this work, we have developed a simulation model to accurately estimate current induced in a multi-mode coil, validated it experimentally and investigated four different multi-mode coil configurations.
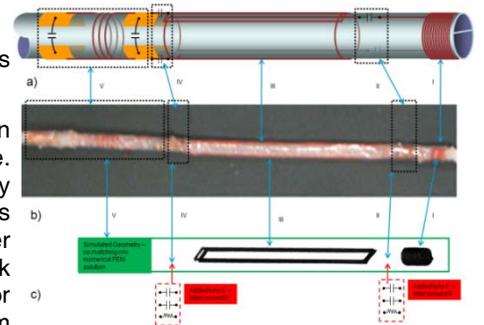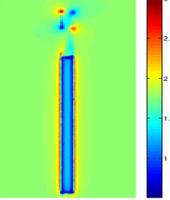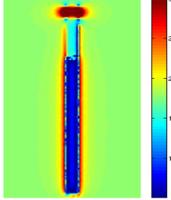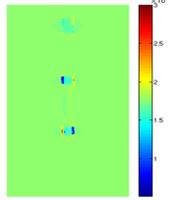

Figure 1 a) Multi-mode geometry b) Fabricated coil c) Simulation model.

An FEM technique was used to simulate the fields produced during actual scanning conditions by modeling the excitation source as an idealized birdcage coil under quadrature excitation in order to calculate the induced current in the device. A simulation model of a multi-mode coil (20-turn tracking solenoid, 3-turn imaging loop, 36 AWG wire, 3cm length, 2mm width) was developed (Figure 1c).

Figure 2: B_1 field maps using Bloch Siegert sequence (left) and FEM simulation (right). Inset: Fast GRE image of multi-mode coil.

With the device placed in the circularly polarized B_1 field, the net field profile in the vicinity of the device was calculated as a superposition of the transmit B_1 field, the scattered field and the field due to induced current in the coil.

For model validation, the Bloch-Siegert B_1 mapping sequence [3] (FOV = 92mmx92mm, acquisition matrix = 256x256, slice thickness = 1.5mm, excitation flip angle = 30˚, 8-ms Fermi-shaped off-resonance pulse at Δ = 4000Hz and flip = 400˚) was used to estimate field profile of a multi-mode coil whose specifications matched the simulation model. The multi-mode coil was precisely positioned in a phantom with 0.9% NaCl solution. The body coil was used to generate circularly polarized B_1 fields. After verification of the simulation methodology, the technique was extended to three other multi-mode coil geometries.
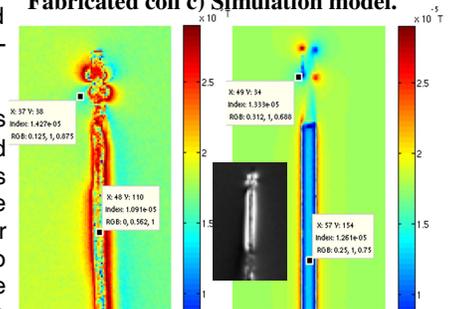
Table 1: Multi-mode coil geometries: Performance Comparison

TRACKING SOLENOID + IMAGING LOOP	TRACKING HELMHOLTZ PAIR + IMAGING LOOP
➢ Verified geometry ➢ Larger longitudinal and radial coverage. ➢ Double tracking peak of solenoid.	➢ Larger longitudinal and radial coverage. ➢ Single tracking peak of Helmholtz pair ➢ Largest overall signal.
TRACKING SOLENOID + IMAGING OPPOSED SOLENOID	**TRACKING HELMHOLTZ PAIR + IMAGING OPPOSED SOLENOID**
➢ Cylindrically uniform. ➢ Smallest induced currents and overall magnitude.	➢ Cylindrically uniform. ➢ Single tracking peak of Helmholtz pair.

Results: Figure 2 shows experimental and simulated B_1 field maps for an oblique slice in plane with the multi-mode coil. A field mismatch of 0.4µT at corresponding points (Figure 2 inset markers) between the measured and simulated values indicates good model validity. Table 1 shows the simulations for the four multi-mode coil geometries considered in the study and a comparative performance analysis.

Discussion and Conclusion: Results show that the Helmholtz pair tracking and rectangular loop imaging multi-mode coil configuration has the largest induced current and best couples with the external coil to magnify the local B_1 field for imaging, while also providing a single tracking peak. The proposed simulation methodology can be used to quickly and accurately optimize geometry to meet application specific requirements and can be extended to study unintended tissue heating caused by guide-wires and implantable devices like stents and pacemakers.

References: [1] Kurpad K, Unal O, JMRI 33, 2011. [2] Kurpad KN, Unal O, ISMRM, 4164, 2010. [3] Sacolick L, et. al. MRM 63, 2010.