Illustration of the Impact of Tuning Configuration on 7T RF Coil Simulations

Joseph V Rispoli[1], Steven M Wright[1,2], and Mary Preston McDougall[1,2]
[1]*Biomedical Engineering, Texas A & M University, College Station, TX, United States,* [2]*Electrical & Computer Engineering, Texas A & M University, College Station, TX, United States*

TARGET AUDIENCE: RF engineers involved with high field simulations of RF coils for coil characterization and safety

PURPOSE: It is common practice to characterize RF coils and establish safety guidelines based on full-wave electromagnetic modeling, typically finite-difference time-domain based methods. It has been recognized that tuning considerations in the model could be frequency-dependent. Specifically, there are two different approaches to tuning and exciting coils in a simulation environment: 1) using phased current sources or altering the value of the distributed capacitors to force an ideal resonant condition[1,2] or 2) specifying actual lumped element component values determined from a physical implementation of the coil, and then using a typical voltage or current source. The two approaches have been reported to produce similar results at 1.5T and 3T,[1,2] and the first approach is typically used in lower field simulations. This abstract uses an example of a loop coil at 7T to illustrate the importance of using the latter approach to tuning for high field simulations, however, as real-life operation off of the resonant condition can significantly change the current distribution with associated ramifications on SAR.

METHODS: A 16-cm loop coil was meshed in commercial FDTD software (XFdtd 7.2, Remcom, State College, PA) and loaded by a custom phantom previously developed for breast and thorax simulations at 298 MHz.[3] The phantom was developed to mimic coil filling in breast imaging of a prone female. The thorax was modeled as a uniform region of muscle, while the breast was a rounded cylinder predominantly modeling fat tissue, with interior regions of mammary tissue. A 4-mm skin layer was located on the exterior of the thorax and breast. Frequency-dependent electrical properties were assigned for all tissues, based on values obtained from Gabriel, et al.[4] The loop coil included 12 equidistant breaks to accommodate placement of a feed and 11 distributed capacitors, and a coplanar shield was spaced 3 mm outside of the coil.[5,6] Two-dimensional geometries were utilized to simulate copper traces on printed circuit board. To model the ideal resonant condition (Approach 1), a series of simulations were performed to determine the distributed capacitor value in the mesh that resulted in a resonant condition at 298 MHz, i.e., the downward zero-crossing of the reactance curve in the frequency domain input impedance plot. To model the actual values (Approach 2), the 11 breaks were populated with 12.1 pF capacitors with 0.1 Ω ESR – a value chosen empirically from a prototype coil that demonstrated uniform current and B_1^+ fields on the bench while enabling matching and tuning with reasonable trimmer capacitor values. A single 50 Ω current source driving a broadband waveform was used for both approaches and spanned the +z coil break. Cell gridding was meshed at no greater than 1 mm for the coil and surrounding phantom, and all curved geometries utilized the software's conformal meshing capabilities. Crucial for simulation stability, the model was surrounded by a quarter-wavelength of free space padding cells, and the boundary comprised seven perfectly matched layers. Simulation convergence was determined by transients dissipating to -40 dB below excitation levels. Steady state field data were calculated on the plane of the coil conductor and the three primary cut planes through the phantom, while SAR data were calculated throughout the phantom. The coil, phantom, and cut planes are shown in Fig. 1.

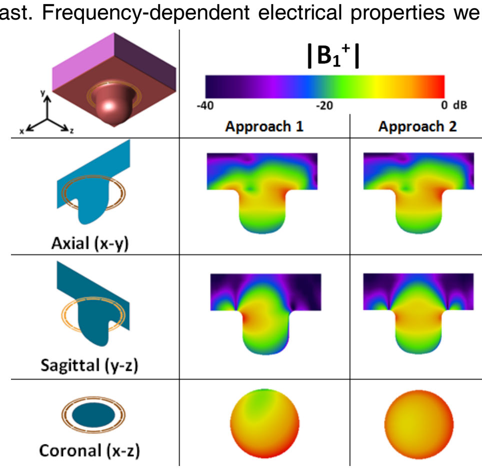

Figure 1: $|B_1^+|$ on the primary planes. 0 dB = 1.5 μT. The phantom (top left) includes skin (red), muscle (magenta), fat, and mammary tissue (not visible)

RESULTS: For Approach 1, simulation results generated the ideal resonant condition with a distributed capacitor value of 43.6 pF with 0.1 Ω ESR. For both approaches, net input power to the coil at 298 MHz was scaled to 1 W. Figure 1 includes $|B_1^+|$ maps inside the phantom on the three primary cut planes. Increased field inhomogeneity is evident in the coronal and sagittal images from Approach 1, with higher and lower field intensity in the -z and +z directions, respectively. A comparison of current density on the coil conductors is shown in Fig. 2. As expected, a majority of current flowed on the edges of the copper trace. However, while Approach 2 resulted in symmetrical, uniform current density around the loop, the resulting current density from Approach 1 is less uniform, with node peaks on opposite sides of the coil. To quantify, the current through capacitors ranged between 102-341 mA for Approach 1 and 240-260 mA for Approach 2. For both cases the maximum 10-g average SAR was located just inside the muscle tissue, and as expected, the $|B_1^+|$ hot spots coincide with the maximum SAR locations. Figure 3 displays SAR in the coronal plane that includes the SAR maximum over the volume. While total power dissipation and average raw SAR in the phantom were approximately equivalent, the maximum 10-g average SAR was 41% higher in Approach 1.

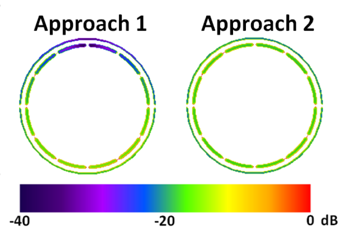

Figure 2: $|J_c|$ (current density) on coil conductors. 0 dB = 200 kA/m^2

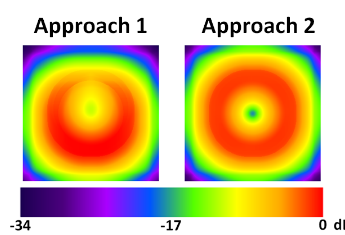

Figure 3: Coronal plane with maximum 10-g average SAR. 0 dB = 1.1 W/kg

DISCUSSION & CONCLUSION: For this coil, the non-uniform current and fields from simulating the ideal resonant case directly resulted in significantly higher maximum SAR. In contrast, the simulation using actual implemented component values exhibited uniform current density, homogeneity, and lower maximum SAR. This example illustrated the sensitivity of modeling results at high fields to lumped element component values, indicating the significance of an approach to simulations that accurately represents the implemented component values rather than using the ideal resonant condition.

REFERENCES: [1] Ibrahim TS, Bio Mag Res (26), 2006. [2] Liu W, eMagRes, 2011. [3] McDougall MP et al. JRMI, in press. [4] Gabriel S et al. Phys Med Biol 41(11), 1996. [5] Lanz T, Griswold M. Proc. ISMRM 2006, #217 [6] Rispoli JV et al. Proc. ISMRM 2013, #5783.