# Building a computational model of a transmit body coil: considerations for RF safety.

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**Purpose** When evaluating the potential for radiofrequency (RF) induced heating of medical devices in a magnetic resonance (MR) environment, it is often necessary to numerically simulate the electromagnetic fields generated by RF body coils. In literature, it is common to find simplified numerical models, which have been shown to accurately simulate the magnetic field of a body coil with a relatively low computational cost[1,2,3]. However, these simplified models were not validated for accuracy with respect to the associated electric field. Accurate modeling of both the magnetic and electric fields might be particularly important for evaluating medical devices that are partially implanted or have external components that are in contact with the body. The aim of this work was to compare three methods of modeling a birdcage coil to determine which of the three most accurately models the magnetic and electric field of a standalone birdcage coil (MITS 1.5T, Zurich Med Tech)[4].

**Methods** The three numerical configurations included a 2-port and a 16-port model with lumped elements, and a 16-port coil model without lumped elements (16-port no-LE). The geometrical model was composed of 16 rungs with dimensions of 600×25×2 $mm^3$ disposed with cylindrical symmetry with a diameter of 740 mm. The rungs were connected at each end by two hexadecagonal rings with a cross section of 40×2 $mm^2$. The shield was modeled by a conductive cylindrical tube (length = 847 mm, thickness = 1.44 mm, diameter = 824 mm). The end rings on the 2-port and 16-port models were interrupted every 140 mm by a 5 mm gap to host lumped elements representing the tuning capacitors. For the 2-port model, the end rings also hosted the two voltage sources used to drive the model. In both the 16-port models, voltage sources were placed in a 7.36 mm gap in the middle of each of the 16 rungs. The lumped elements located in the end rings consisted of a capacitance and a resistance in parallel. To obtain a circular polarized field, the sources were out of phase both in space and time by 90° for the 2-port model and 22.5° for both the 16-port models. Full wave electromagnetic numerical simulations were performed using commercially available software (xFDTD, Remcom Inc. and SEMCADX, SPEAG). The model resolution was 3×3×3 $mm^3$ and a time step was 4.03 ps. A broadband excitation was used to refine and verify the values of the tuning elements. A sinusoidal excitation at the coil resonant frequency (63.6 MHz) was used to generate the EM field. The simulated field distributions were compared to field measurements from a transmit body coil with the same geometrical characteristics and resonant frequency as the numerical coil (**Fig. 1**). The measurements were performed using the Dosimetric and near-field assessment Acquisition SYstem (DASY5NEO, SPEAG)[4] and compatible field probes (ER3DV6 isotropic electric field; H3DV7 isotropic 3-dimensional magnetic field, SPEAG). For comparison purposes, each simulated field distribution was normalized to the measured magnetic field amplitude at the isocenter of the body coil.

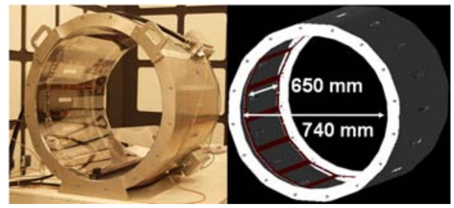


*Figure 1: physical coil and numerical model*

**Results** The voltage sources on the both the 16-port models had a uniform frequency response around the 63.6 MHz resonant frequency (**Fig. 2a**). The capacitance and resistance of the lumped element was initially assessed theoretically and then refined numerically for final values of 63.5 pF and 1140 Ω, respectively. The capacitance was chosen such that the numerical coil was circularly polarized and resonant at 63.6 MHz (**Fig. 2a**), and the resistance was used for power matching at 63.6 MHz. The same lumped element values were used in both the 2-port and 16-port models. At the resonant frequency, all three models produced a circularly polarized homogeneous magnetic field (**Fig.2c**). There was, however, substantial variation in the electric field. **Fig. 2b** shows the amplitude of electric field along the longitudinal axis of the coil (z). **Fig 3** shows the measured and simulated amplitude of electric field distributions in the axial and coronal planes.

**Discussion** The measured electric field distribution was asymmetric at the isocenter of the coil (32.5 cm) along the longitudinal (z) axis (**Fig.2b**). Both the asymmetric field distribution and the local minimum of the electric field were accurately captured by the 2-port model with the measured and simulated local minima located 31.5 cm and 31.6 cm from the feed points, respectively. While the asymmetry was captured by the model, the measurements showed a 10% variation in the electric field maxima, while variation in the simulations was 7%. Both of the 16-port numerical models simulated an electric field distribution symmetric at the isocenter of the coil along the z-axis (**Fig.2b**). One of the most significant variations in the accuracy of the coil models was the amplitude of the electric field in a circular cross section of the central axial plane (**Fig. 3**, black dotted circle, diameter = 42 cm). Within the circular cross section, the measured electric field was relatively uniform with amplitude of 7.2 ± 1.88 V/m. The 2-port, 16-port and 16-port no-LE models simulated an amplitude of 9.4 ± 2.18 V/m, 4.7 ± 1.85 V/m, and 196.8 ± 82.10 V/m, respectively. While within the circular cross section both the 2-port and 16-port models showed good agreement with the measured field values, it is obvious that the 2-port model better represents the measured field distribution near the sources (red arrows in **Fig.3**). In the central coronal plane, the electric field distribution of the 2-port and 16-por models agree well with the measured data, whereas, the electric field distribution of the 16-port no-LE differed substantially from the measurements; within the circular cross section (**Fig. 3**, red circle, diameter = 42 cm) the mean values were: 55.4 ± 26.39 V/m, 51.6 ± 23.72 V/m, 53.6 ± 25.19 V/m, and 117.1 ± 54.9 V/m for the measurements, 2-port, 16-port, and 16-port no-LE models respectively.

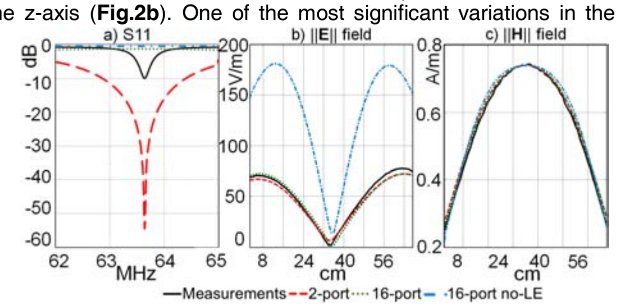


*Figure 2: a) S11 vs freq.*
*b-c)* ***E*** *and* ***H*** *fields amplitudes along the z axis*

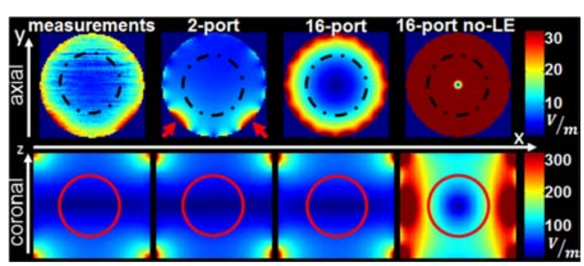


*Figure 3:* ***E*** *field amplitude on central axial and coronal sections*

**Conclusions** The experimental validation showed that all three of the numerical models properly simulated the magnetic field distribution. However, to represent the true electric field and avoid possible overestimation by several orders of magnitude, proper modeling of the tuning capacitors, coil losses, and source configuration was required.

**References.** (1) Collins CM and Smith MB. Magn Reson Med 2001; 45: 684–691. (2) Murbach M et al. Progress in Biophysics and Molecular Biology 107 (2011) 428-433. (3) Ibrahim TS et al. IEEE Trans Biomed Eng. 2005 Jul;52(7):1278-84. (4) Neufeld E et al. Phys. Med. Biol. 54 (2009) 4151–4169.