Accurate phased array modeling in the presence of coupling

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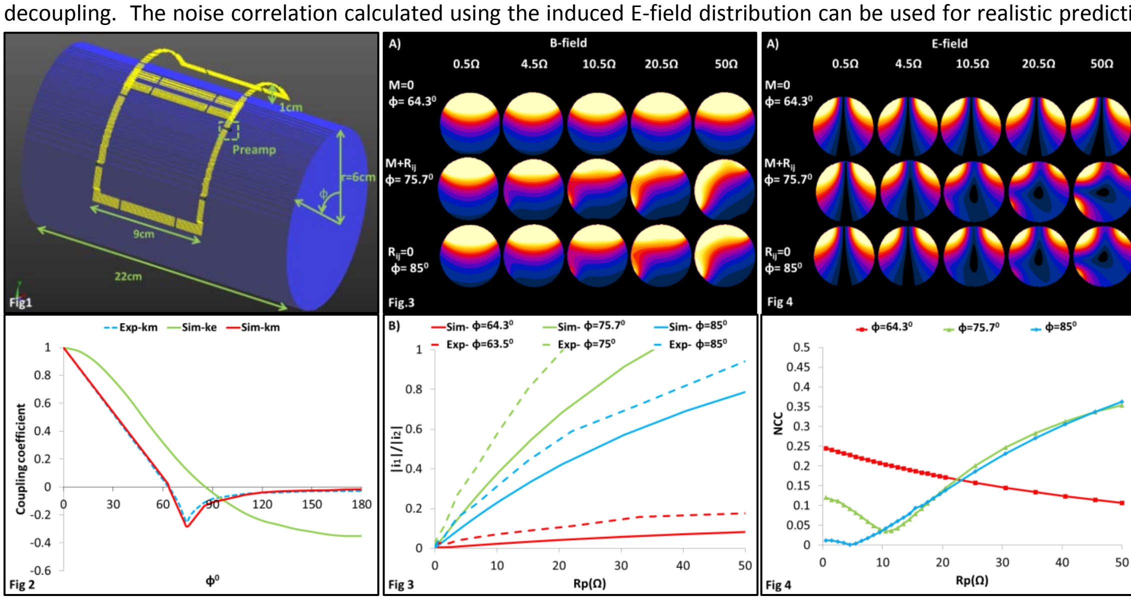
Introduction: Optimized MRI phased array design often requires accurate simulation of electromagnetic fields that take into account wave behavior at high B0 fields. In addition, accurate modeling of construction techniques such as array overlap and realistic array components such as cables, decoupling traps, and preamplifiers and there effects on decoupling and SNR/g [2] is also becoming important to array designers for maximizing performance. Overlap and preamp decoupling are widely used methods to minimize the cross talk induced by mutual inductance [1]. We report on a simulation method that incorporates both resistive and mutual inductance coupling and a preamplifier model accurately depicting the preamplifier de-coupling effect in phased array simulations and compare with bench measurements.

Theory and Methods: Simulations of array elements with realistic decoupling networks will alter the voltage/current induced ("cross-talk") in other array elements coupled through mutual inductance and shared resistance, therefore altering both the B1 field and the J/E field within the sample. If the "noise correlation" N_{ij} is calculated using the traditional $N_{ij}=\sigma\int E_i \cdot E_j \, dV$ where σ is sample conductivity, E is the electric field in the sample volume V, determined from the FDTD simulation, then this noise correlation matrix will contain the effects of mutual inductance cross-talk. Electromagnetic fields of two 9-cm saddle loops on a 14cm diameter cylinder, using a cylindrical phantom 22 cm long and 12cm in diameter were determined at 123MHz (3T) with a finite-difference time domain (FDTD) method (SEMCAD X v14.8, SPEAG, Zurich, Switzerland). Noise correlation analysis was performed using Musaik (SPEAG, Zurich, Switzerland). Geometrical models: The angular position of the second loop was varied to determine the mutual inductance and shared resistance dependence, and preamplifier decoupling dependence on the B1-field, E-field and Noise Correlation, tested for three particular cases: $\phi=64.3^0$(zero mutual inductance), 75.7^0(mixed coupling), and 85^0(zero shared resistance [3]). Eight capacitors (53pF) are placed on each loop. The preamplifier input circuit was modeled as a matching capacitor ($X_m = 1/\omega C_m$) with a parallel resonant LCR network, where R_p represents the input impedance of the preamplifier in a range of 0.5Ω to 50Ω shown in Fig.1 and preamp decoupling by X_m^2/R_p. The current ratio of the induced secondary loop current relative to the primary current is determined through simulation or experiment using a network analyzer (E5061B, Agilent, Santa Clara, USA).

Results and Discussion: Unloaded simulation/experimental inductive coupling (k_m) with loop angle separation (Fig2) show similar null (M=0) at $\phi=64^0$ and negative maxima at $\phi=74.5^0$, while simulated shared resistance curve shows that zero shared resistance occurs at $\phi=85^0$ (Fig.2-k_e=0). As preamp input resistance R_p is increased, more current (cross-talk) is induced in the secondary loop. In Fig.3A the B-field under the region of the secondary loop (left) is enhanced as R_p is increased, and more prominent when M≠0. This current coupling increase with R_p is also seen in the Fig. 3B, strongest (slope), where the mutual inductance is strongest ($\phi=75.7^0$). The E-field maps in Fig.4A show the same strong dependence on preamp resistance when there is mutual inductance present, weak dependence in the M=0 resistive coupling only case ($\phi=64^0$). Fig.4B shows simulated noise correlation coefficient (NCC) for different preamp resistances. When mutual inductance cross-talk is the only coupling ($\phi=85^0$), perfect preamp decoupling occurs NCC≈0 for Rp < 4.5 Ω and NCC increases as a higher R_p is used. However, when R_p< 4.5Ω, a large loop voltage makes the loop behave as an antenna with a NCC >0. Preamp decoupling cannot remove cross-talk from shared resistance coupling so NCC does not reach zero for $\phi=64^0$ and 75.7^0 (Fig.4B-Red,-Green). Notice a minimum in the NCC at about R_p = 10Ω for the case where both resistive and inductive coupling exist (Fig.4B-Green), and the decrease in NCC with R_p for the zero-inductive coupling case (Fig.4B-Red), both interesting consequences of the N_{ij} 3D integration.

Conclusion: We have demonstrated that both mutual inductance and shared resistance can be accurately simulated as well as preamplifier decoupling. The noise correlation calculated using the induced E-field distribution can be used for realistic prediction and optimization of SNR and g-factor for coupled phased array coils.



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