Models of Parasitic Mutual Capacitance in Array Coils: Effects on Mutual Reactance, Resistance and Noise Correlation

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Introduction: Parasitic capacitive coupling is an important component of array coil coupling, especially at higher frequencies, but it is often neglected, or compensated ad hoc, even though it has significant effects on coil tuning, matching, and overall coupling. To the best of our knowledge, quantitative models to describe and predict capacitive coupling in array coils do not exist in the literature. We present a general strategy for modeling capacitive coupling that leads to simple lumped-element circuits. The method also suggests how, along with tuning capacitor distribution (1) and coil overlap, intentional capacitive coupling (e.g., using capacitive decoupling networks) can be used to manipulate not only the mutual reactance between coils (2, 3), but also the mutual resistance, which is often assumed to be determined by geometry alone (4, 5).

Materials and Methods: In the 2-coil circuits of Figure 1, coils are segmented into sections with parasitic capacitive coupling (1' and 2' in Fig. 1a) and those where capacitive coupling is negligible. The parasitic mutual capacitance, C_{12} can be modeled either as lumped capacitors in parallel with the intentional mutual capacitance, C_2, (Fig. 1b) or as a distributed capacitance (Fig. 1c). The distributed model includes mutual resistance and inductance between all segments and assumes that the parallel capacitance and series impedance of these segments is distributed uniformly. Simulations of the impedance (Z) parameters between the coil ports are performed with HFSS at 127.8 MHz (Ansys Corp., USA) for two overlap situations and various values of C_2 and C_3 (Fig. 2). The coils are modeled as copper traces with a thickness of 40 µm on a 7 mm substrate (ε_r = 3.4 for PMMA) over a large lossy dielectric phantom (ε_r = 76, σ = 0.8 S/m). C_{12} as well as the self and mutual impedance of all the segments required least squares fitting in MATLAB (The MathWorks, USA) for each model and overlap situation. A gapped array (Fig. 2a) was built with the same dimensions as the simulation; it was tuned and matched for each value of C_3, and connected to low-input-impedance preamps (Philips Healthcare).

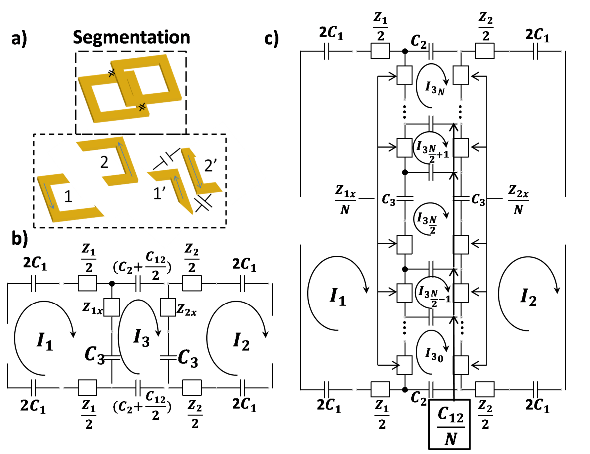

Figure 1: (a) coils segmented into regions with (') and without mutual capacitance, C_2+C_{12}; (b) lumped and (c) distributed capacitance models. C_1 compensates for the inductance of the coil and along with C_3, splits the coil into sections < λ/20.

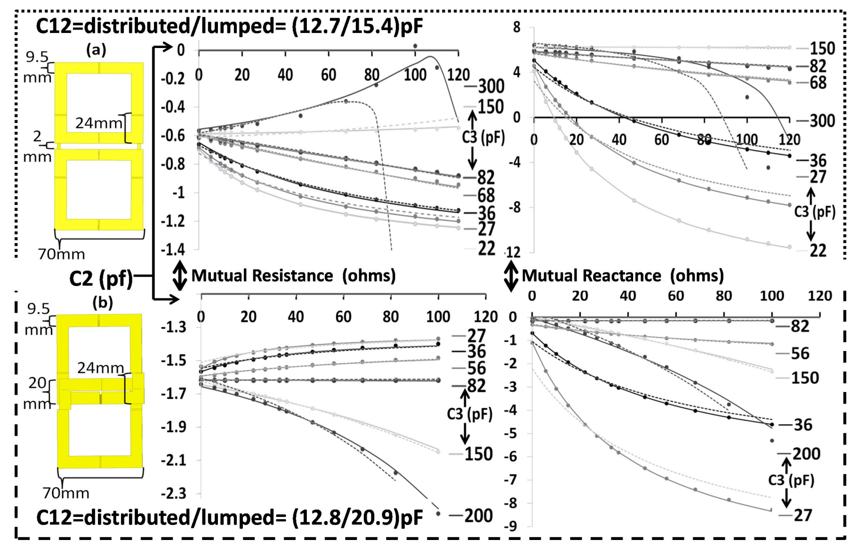

Figure 2: Two-port mutual Z-parameters for coils (a) separated by 2 mm and (b) overlapped by 20 mm. In overlapped coils the strip rises 2 mm above the substrate at C_1 and returns at C_3 to avoid intersection. Dots are found with simulation, solid lines by distributed circuit model and dashed lines by lumped capacitance model (Figure 1b). The parasitic capacitance predicted from least squares fitting is listed for distributed and lumped models.

Measurements are taken on a 36×26×11 cm^3 phantom filled with demineralized water and 3.6 g/ℓ NaCl and 1.96 g/ℓ $CuSO_4 \cdot 5H_2O$ corresponding to the simulated phantom. Noise correlations predicted from the measured and simulated Z parameters (6) are compared to those measured from scans without RF excitation.

Results: Fits of the simulated mutual impedances using both circuit models are shown in Fig. 2, including one value of C_{12} for each combination of model and overlap geometry. The distributed model of Fig. 1c) fits the data substantially better than the lumped model only for the gapped array at large values of C_3. As shown with the gapped array when C_3=300 pF and C_2>80 pF both models become inaccurate when the coils and added capacitors form a third resonant circuit which introduces a large impedance in series with the two coils. Without intentional C_2 added, the coil self-resistance of the gapped and overlapped arrays varies in a narrow range from 4.36 Ω (C_3=27 pF) to 4.79 Ω (C_3=300 pF) and 3.90Ω (C_3=27 pF) to 4.22 Ω (C_3=300 pF), respectively. The change in self-impedance due to mutual capacitance (C_2 and C_{12}) is equal in magnitude, but exactly opposite to the change in mutual impedance. Therefore, only the mutual impedances are shown in Fig. 2. The fitted parasitic capacitance C_{12} (Fig. 1) is in good agreement with the analytical result (13.3 pF) based on quasistatic conformal mapping with multi-planar structures (7). Figure 3 demonstrates how, in the gapped array, C_2 and C_3 can be adjusted to change the noise correlation from 0.14 to a negligible value of 0.02. This is not achievable with overlapped arrays (Fig. 2b).

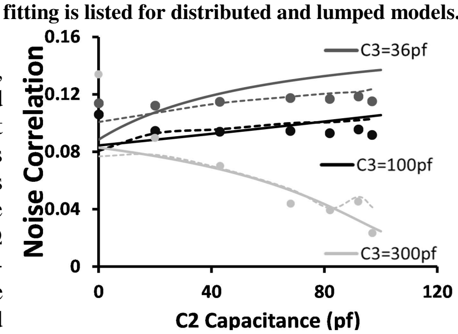

Figure 3: Noise correlations (magnitude) for the gapped array (Figure 2a). Dots are noise scans; solid and dashed lines are predictions with fitted and measured Z-parameters, respectively.

Discussion and Conclusion: The distribution of capacitance on array coils has been known to affect coupling (1). Our models of capacitive coupling are the first to be quantitatively validated for MRI coils. The effective parasitic capacitance can be quantified and it closely matches the analytical result of two coupled strips (7), confirming its physical origin. The models also show how mutual resistance and/or reactance can be adjusted by varying series capacitive splitting and inter-element capacitors (8). In the gapped array, inter-element capacitors allow noise correlation to be nearly eliminated without altering coil geometry or using coil combinations (9). This is not possible with the overlapped array, suggesting that overlapping is not only unnecessary with preamp decoupling, but also undesirable. Applications include arrays used for reception as well as transmission.

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Refs: 1. Wei J et al. Conc. MR Part B 29B:50 **2.** Wu B et al. Conc. MR Part B 31B:116 **3.** Zhang X et al. JMR 9;170:149 **4.** Redpath TW. MRM 24:85 **5.** Roemer PB et al. MRM 16:192 **6.** Brown R et al. MRM 58:218 **7.** Chen E et al. IEEE Trans. MTT 45:939 **8.** Li Y et al. Med. Phys. 38:4086 **9.** King SB et al. MRM. 63:1346