Comparison of Arrays with Various Mutual Impedances: Noise Correlation, SNR and Parallel Imaging Performance

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Introduction: Superior parallel imaging performance is typically achieved with a sufficient number of elements, good isolation and spatially unique sensitivities (1). Isolation depends on the mutual impedance between coils, while its resistive component is the source of intrinsic noise correlation (2)(3), i.e., the correlation in absence signal crosstalk. Standard decoupling schemes such as those using reflective preamps or capacitive networks remove only the mutual reactance between coils (4-7). Previous works have stated that intrinsic noise correlations "...are impossible to reduce in a lossless way."(8). Here we present a method that uses inter-element capacitors to remove mutual resistance in addition to mutual reactance, thereby improving isolation and eliminating noise correlation. This approach is applicable to arrays with large noise correlations (>0.3) between adjacent elements (9) and for transceive arrays (10) where amplifier decoupling (11, 12) in transmission is much more difficult to achieve than in reception.

Materials and Methods: Parasitic or intentional capacitance between adjacent coils (Figure 1) introduces an additional mesh whose current allows the removal of both reactive and resistive parts of the mutual impedance (Maunder et al., this conference). The effect depends on the choice of series capacitance (C_3 in Fig. 1a) and inter-element capacitors (C_2) in addition to the spacing between coils. We investigate this approach with two- and four-coil linear arrays without overlap as shown in Figure 1. In the two-coil array a separation of 5 mm is chosen so the mutual impedance can be completely removed with C_2 and C_3 equal to 68 pF and 300 pF, respectively (all capacitors 700B series, American Technical Ceramics; USA). For the four-coil array in Figure 1b) the capacitors C_d and C_b adjust the mutual reactance, while C_a capacitors remove mutual reactance by driving a current in the mesh between coils. This scheme allows the spacing to be chosen independently as 3 mm. Three cases are compared: zero mutual reactance (while mutual resistance is unmodified or increases), zero mutual impedance (both mutual resistance and reactance reduced to negligible levels) and no decoupling (no decoupling capacitors C_2, C_a or C_d added). Gradient-echo imaging (T_R/T_E = 11/1.95 ms, pixel bandwidth = 727.2 Hz, acquisition matrix 256 × 256, FOV = 30 cm, 1 average) is performed on a 36×26×11 cm^3 phantom filled with 3.6g/ℓ NaCl and 1.96g/ℓ $CuSO_4{\cdot}5H_2O$ (ε_r = 76, σ = 0.8 S/m). Scans without RF excitation were acquired to measure noise covariance. Active PIN diode detuning traps are placed on the series capacitors (C_{tn}, C_3 and C_{bn}), and ports are connected to low-input-impedance preamps (Philips Healthcare) through λ/2 coax cables and baluns.

Results: Figure 1 (a) and (b) shows SNR maps using optimal SNR reconstruction in a sagittal slice through the center of the coil arrays. The SNR of the two-coil array with no mutual impedance is greater near the surface because the third shared loop picks up significant signal superficially. In this case there is a slight decrease in SNR farther into the phantom between the coils Figure 1a), likely due to signal cancellation from the shared loop. In the four-coil arrays the high impedance at the coil ports is in series with the shared mesh and the current is not enhanced by resonance. Figure 1c) shows the SNR as a function of depth into the phantom averaged along the coil array length. The average for the four-coil array is over the slice shown, while for the two-coil array it includes two additional sagittal slices (±2.5cm). Comparing the three cases the average SNR is nearly indistinguishable, with differences within 2%. For the four coil-arrays, the average measured self-resistance for no mutual impedance/no decoupling/no mutual reactance versions was 6.7/5.6/6.2 Ω, while the mutual impedance between adjacent coils before adding matching circuitry is 0.093–j0.16 / 0.42–j6.1 / 0.44+j0.18 Ω. The magnitude of the noise correlation measured in the two-coil array with no mutual impedance, no decoupling and no mutual reactance was 3.2/13.3/14.0%.

Noise Correlation matrix (%) no mutual impedance/no decoupling/no mutual reactance			
99.3/100/100			
1.28/4.09/12.3	100/99.4/99.7		
5.00/0.93/4.96	1.65/3.53/5.16	99.3/99.5/98.7	
1.38/0.28/1.38	8.03/6.76/6.54	0.90/7.95/9.65	100/99.5/99.2

Table 1: noise correlation in percent for decoupling condition separated by slashes with the order shown in the heading. The diagonal shows noise standard deviation compared to the maximum

SENSE Acceleration	1/g factor mean/min slice 2		
	No mutual impedance	No decoupling	No mutual reactance
2	0.99/0.84	0.98/0.81	0.99/0.80
3	0.93/0.70	0.91/0.74	0.92/0.48
4	0.88/0.03	0.88/0.02	0.91/0.28

Table 2: 1/g-factors for 4-coil arrays up to an R of 4

Noise correlation matrices for the four-coil arrays are shown in Table 1; the diagonal shows the noise standard deviation normalized to the largest value among coils. As expected the noise correlation between adjacent coils is very small (≤1.7%) when the mutual impedance is completely cancelled. Noise scans with channels terminated in 50 ohm loads instead of coils resulted in an average noise correlation of 1.3%, which sets the lower bound of measurable noise correlation using the available preamplifier box. The 1/g-factors shown in Table 2 and Fig. 1b) do not indicate systematic differences between the three tuning arrangements, with slightly better performance at R=4 in the no mutual reactance case.

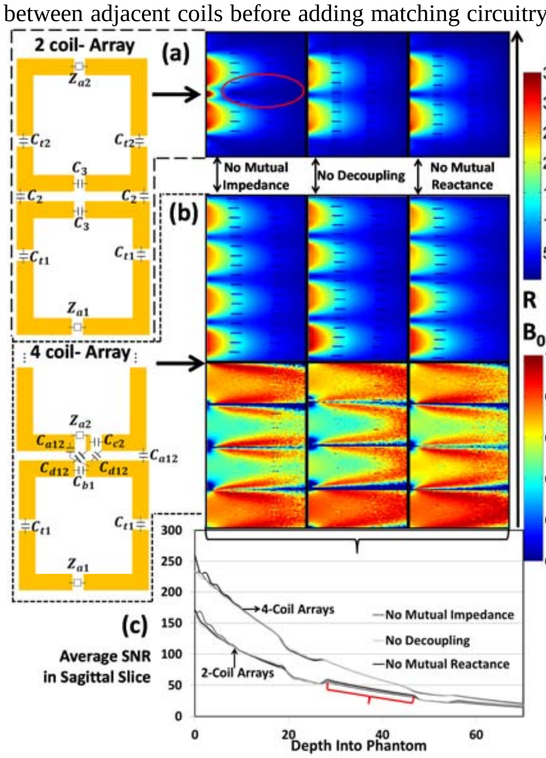

Figure 1: optimal reconstruction SNR maps and coil diagrams for (a) two-coil arrays and (b) four coils arrays with 1/g factor maps and (c) SNR in sagittal slices with depth. The red oval in (a) and red line in (c) indicate decreased SNR for the removed mutual impedance

Discussion and Conclusion: This scheme allows cancellation of both components of the mutual impedance without changing the geometrical arrangement of coils. Arrays with only preamplifier decoupling and those with zero mutual reactance perform mostly the same in terms of SNR and parallel imaging, consistent with previous studies showing minor differences with small levels of crosstalk (3, 13). In addition, the reduction of mutual resistance (and therefore intrinsic noise correlation), which has not been previously addressed in this manner, does not seem to affect the average SNR or parallel imaging performance significantly. Future work includes applying this method of completely removing mutual impedance in transmit coils.

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