NOVEL METHOD TO ESTIMATE COIL COUPLING FOR ENHANCED TUNING AND PARALLEL IMAGE RECONSTRUCTION

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Introduction:

For MRI coil arrays having many channels, it is generally difficult to achieve effective isolation of channels by overlapping coil loops. Preamplifier decoupling is thus the major technique used for isolation, reducing inductive coupling across channels through constraint of current flow in the loops [1]. A novel coupling matrix method has been developed to model the preamp decoupling mechanism permitting selection of components for optimal isolation. The model may further be used to estimate coupling of coil sensitivity matrices and noise correlation in SENSE reconstruction [2], allowing for enhanced parallel imaging quality. The coupling matrix retrieved from reconstructed images using an experimental head array (Fig. 1) has been found to be consistent with that estimated using the proposed model-based method.

Figure 1

Coupling Matrix Model:

In the general coil circuit with preamp decoupling in Fig. 2 [3], the mutual inductance between the two channels causes the induced voltages to be interdependent before the preamp stage. This coupling was modeled by a matrix $\mathbf{C}$ such that $\mathbf{V}_{out} = \mathbf{CV}$, where $\mathbf{V}$ represents the original signals induced across coil loops and $\mathbf{V}_{out}$ contains the mixed signals to be amplified. If we assume all channels are matched and tuned with identical components, the normalized coupling matrix may be derived as $\left| \mathbf{C}_{ij} / \mathbf{C}_{jj} \right| = kQ/\left(1 + Z_0 / R_p\right)$, where R_p is the preamp input impedance, Z_0 is the matching impedance,

Figure 2

k is the mutual coupling coefficient and Q is the loaded Q factor of the loop. With impedance and isolation measurements, the coupling matrix can be estimated from the circuit model. Conversely, given a target isolation, the coupling matrix may be used to calculate optimal specifications for circuit components in the coil design. Additionally, the coupling matrix may be used in SENSE reconstruction through estimation of the coupled noise correlation matrix, $\mathbf{C\Psi C}^T$, where intrinsic noise covariance Ψ can be simulated by computational electromagnetic methods.
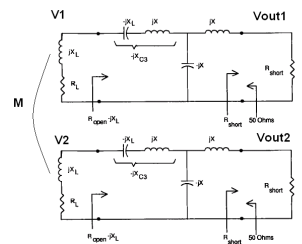
Simulations:

Synthetic phantom and coil sensitivity maps were generated to evaluate SENSE reconstruction quality. In Fig. 3, the black line (circles) depicts the SNR of the SENSE reconstruction given an independent noise source, the red line (triangles) that for correlated noise ($\left| \mathbf{C}_{ij} / \mathbf{C}_{jj} \right| = 0.01$, $\Psi_{i \neq j} = 0.3$) when using the conventional diagonal noise correlation matrix, and the blue line (squares) depicts the reconstruction results for the same correlated noise when using the estimated coupled noise covariance matrix. For strongly coupled or high density coil arrays, the off-diagonal terms of the covariance are not negligible and appreciable SNR gain may be obtained by utilizing the coupling matrix information in image recon.
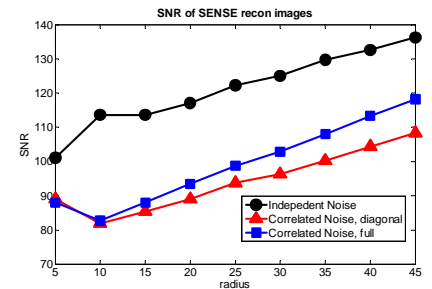

Figure 3

Experimental Results:

A 4-channel head array was built using non-overlapped coil loops and un-tuned preamp decoupling (Fig. 1) to effect strong coupling. The coil array was tested on a GE 1.5T system with a ball phantom using both sequential (isolated channels) and simultaneous (coupled channels) data acquisition. The coupling matrix was estimated from the coil circuit model, and validated from reconstructed images by $\hat{\mathbf{C}} = (I_{Seq}{}^T I_{Seq})^{-1} I_{Seq}{}^T I_{Sim}$. Fig. 4 depicts reconstructed magnitude images from all channels. Coupling effects are readily observed between adjacent neighbor channels for simultaneous acquisition (right) when compared to sequential acquisition (left). Estimation of the normalized coupling matrix (in magnitude) from the coil model is consistent with the results from the imaging data (Table 1). In coil array design, accurate coupling matrix modeling may be further used to determine supplemental phase shifting to achieve better uniformity of sensitivity maps.
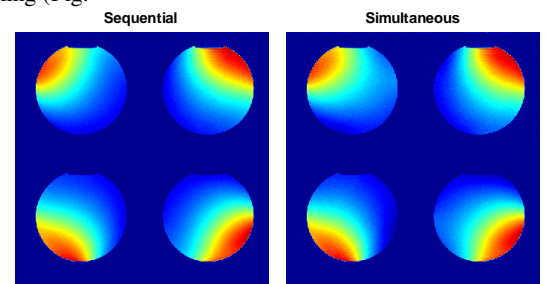

Figure 4

References:

[1] P. B. Roemer, et al., "The NMR phased array," *Mag. Reson. Med*, vol. 16, pp. 181-191, 1990.

[2] K. P. Pruessmann, et al., "SENSE: Sensitivity encoding for fast MRI" *Mag. Reson. Med*, vol. 42, pp. 952-962, 1999.

[3] Reykowski, A. et al., "Design of Matching Networks for Low Noise Preamplifiers" *Mag. Reson. Med*, vol. 33, pp. 848, 1995.

Model-based	Image-based	1		2		3		4	
	1	1.0000	1.0000	0.2894	0.2816	0.0518	0.0403	0.1100	0.0917
	2	0.1883	0.1994	1.0000	1.0000	0.0696	0.0453	0.0614	0.0451
	3	0.0670	0.0790	0.1381	0.1540	1.0000	1.0000	0.1974	0.2002
	4	0.0931	0.1092	0.0798	0.0859	0.1293	0.1172	1.0000	1.0000

Table 1: Coupling Matrix Model Evaluation