Do We Need Preamplifier Decoupling?

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Introduction

Preamplifier decoupling is an established method to minimize the effects of mutual inductance between coil elements in array coil design [1, 2].
The method greatly simplifies the tuning and matching procedure and allows image combination by simple square-root-of-sum-of-squares (SOS) method. However, it can be shown that similar combined SNR results can be achieved without preamplifier decoupling, even in the presence of significant inter-coil coupling, as long as the coils are tuned and matched properly and the data are combined using optimum weighting as defined by Roemer et al [3].

Theory

Figure 1 shows two coil arrays terminated with preamplifiers having identical noise parameters. In case (a) the preamplifiers are utilizing the preamp decoupling technique (=high impedance at the coil port), in case (b) the preamplifiers have arbitrary input impedances. In the equivalent circuits shown, all signal and noise sources are modeled as discrete voltage and current sources concentrated at the coil input terminals. It can be shown that there is a linear relationship between the port voltages for case (a) and (b):

$$\begin{bmatrix} V'_{in1} \\ \cdot \\ \cdot \\ V'_{inN} \end{bmatrix} = \mathbf{T} \cdot \begin{bmatrix} V_{in1} \\ \cdot \\ \cdot \\ V_{inN} \end{bmatrix}$$

with

$$\mathbf{T} = \left(\mathbf{E} + \mathbf{Z} \cdot diag\left(\frac{1}{Z_{in1}} \cdots \frac{1}{Z_{inN}} \right) \right)^{-1}$$

Where **E** is the identity matrix, **Z** is the impedance matrix for the coil array and $Z_{in1}..Z_{inN}$ are the input impedances of the preamplifiers. Since the relationship between the original receive signals $\mathbf{V_{in}}$ and the modified receive signals $\mathbf{V'_{in}}$ is linear, it follows that the same SNR can be achieved in both cases provided that the inverse of **T** exists and optimum signal weighting and combination is performed in both cases.

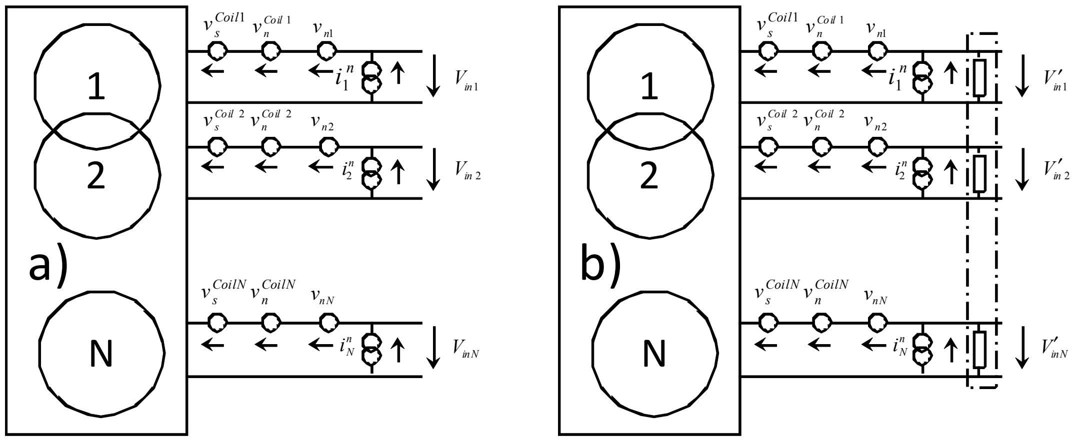

Figure 1: Coil Array with signal and noise sources from all coil elements as well as noise voltages and noise currents from all preamplifiers a)Preamplifiers have open input (=preamplifier decoupling) b) Preamplifier have arbitrary input impedances $Z_{in1}..Z_{inN}$

Methods and Results

Using a least-square fitting method [4], the correct noise match impedance Z_{opt} for two 1.5T preamplifiers was determined to be ~35Ω. A set of tightly coupled rectangular coils was build, matched and tuned to Z_{opt} using resistive loads and an oil phantom. A first set of matching networks was designed and build to provide preamplifier decoupling for both coils. A second set of matching networks was designed similar to the first set but with the addition of two 90° phase shifters with a characteristic impedance of 35Ω. By placing these phase shifters between the preamplifiers and the decoupling matching networks, the coils were shifted from a "preamp decoupled" to a resonant state. In the resonant state, the input impedance under load on either channel changed from 35Ω to 16Ω due to strong coupling. Leaving all other parameters untouched, two sets of SNR data were obtained, one for the preamp decoupled case and one for the resonant case. Fig. 2 shows the results obtained for both cases. In the preamp decoupled case, the individual channel SNR maps show a clean separation of the two coil channel sensitivity maps (a,b). In the resonant case two modes are visible that extend across the field of view for both coils (d,e), indicating significant coupling between the two channels. However, when comparing the SNR maps for the combined signals, the resonant case shows almost identical values as the preamp decoupled case (c,f). Local SNR is reduced by no more than 3%.

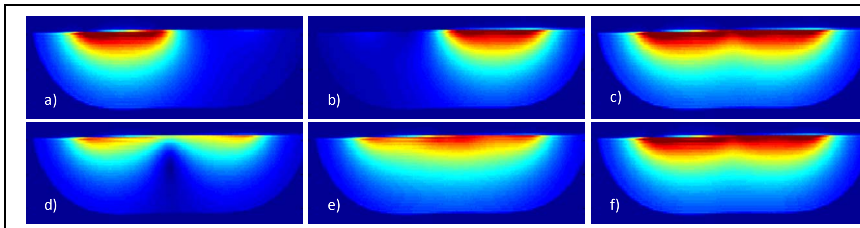

Figure 2: Results from the experiments: a,b) Individual channel SNR map for the preamp decoupled case; d,e) Individual channel SNR map for the resonant case; c,f) combined SNR maps for the preamp decoupled and the resonant case respectively.

Discussions and Conclusion

The presented theory and our initial results suggest that MRI arrays can be build without preamp decoupling even in the presence of significant inter-coil coupling. SNR may actually be improved by drastically simplifying the matching networks and reducing the associated loss in SNR. Several conditions need to be met in order to achieve this goal: 1) All individual channels have to be optimally tuned and matched in the absence of any coil coupling (= all other channels detuned) 2) The data from all active and tuned coil channels need to be used for the image combination. Unused channels need to be completely detuned. 3) Optimum weighting and combination of all channels is required. 4) For certain NMR applications, preamp decoupling may still be preferred in order to reduce ring-down time or attenuation of the spin sample [5].

References [1] Roemer et al., The NMR Phased Array, MRM 16, 192-225, (1990). [2] Reykowski et al., Design of Matching Networks for Low Noise Preamplifiers, MRM 33, 848-852, (1995). [3] Findeklee, Proc. ISMRM 2009, 508. [4] Caruso et al., Computer Aided Determination of Microwave Two-Port Noise Parameters, IEEE Trans Microw Theory Tech, Vol. MTT-26, No. 9, September 1978. [5] Hoult, Fast Recovery with a Conventional Probe, JMR 57, 394-403 (1984).