Noise correlation and coupling mechanisms: a comparison of overlapped and non-overlapped surface coils at 3T

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Introduction

In surface coil arrays overlap is a common method of geometrically decoupling nearest neighbors to minimize mutual inductance. Other methods such as preamplifier decoupling (1) are used to reduce inductive coupling among non-nearest-neighbors, as well as that due to other mechanisms. Noise correlation is a common measure of overall coupling and is used in this work to investigate the effect of coil overlap and sample losses on coupling. The results suggest that in realistic imaging conditions at 3 T to avoid coil coupling it is preferable to avoid coil overlap when effective preamp decoupling is used.

Materials and Methods

An array of seven 10×20 cm^2 independent rectangular coil elements were connected to a universal interface box (2) and positioned below a 30 ℓ acrylic tank having dimensions $80 \times 25 \times 15$ cm^3 ($l \times d \times h$). Each coil element includes an impedance matching network and low-noise preamplifier (optimal noise figure 0.5 dB) on a circuit board adjacent to the rectangular loop. Impedance matching was such that a preamp decoupling (1) impedance of 1 kΩ was present at the loop's terminals, while the loop's resistance was measured as 1.5 Ω unloaded and 33 Ω loaded with a solution mimicking tissue loading. The 1 kΩ impedance ensures that substantial preamp decoupling is achieved even in the presence of loading greater than that achieved by soft tissue. Electrical adjustments are unnecessary to account for different amounts of inductive coupling encountered with different coil arrangements.

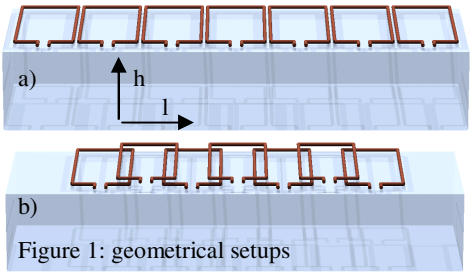

Figure 1: geometrical setups

A first set of noise measurements was performed with the coils placed such that the long sides were almost touching, i.e., in conditions of nearly maximal inductive coupling (Fig. 1a). The tank was initially left empty, then filled with 30ℓ of demineralised water in which sodium chloride (NaCl) was subsequently dissolved to reach a maximal concentration of 180 mM in steps of 9 mM (100 mM corresponds to physiological saline, while ~50 mM is appropriate to mimic coil loading due to soft tissue).

At each concentration 2^{18} noise samples were acquired in absence of RF excitation with a 245 kHz bandwidth using a Philips 3 T Achieva spectrometer. A second set of identical measurements was performed with the coils overlapped by 2 cm such that the mutual inductance between nearest neighbours is approximately zero (Fig. 1b). Noise correlation coefficients between channels were calculated from the noise samples using standard functions in Matlab (The MathWorks, Natick, MA, USA).

Results and Discussion

The data in Fig. 2 shows, as a function of NaCl concentration, the average magnitude of noise correlation coefficients on the first, second, and third off-diagonals of the correlation matrix, reflecting neighbour, next-neighbour, and second-next-neighbour coupling, respectively, as well as the overall mean. The complete matrix is shown for a concentration (54 mM) that simulates tissue loading. Without loading (i.e., in air) noise correlation arises only from noise produced in the coil conductors and coupled inductively to other coils. The modest difference in measured correlation is evidence of effective preamplifier decoupling even though there is a large difference in mutual inductance in the two overlap situations. With initially lossless, highly dielectric demineralised water ($\varepsilon_r \approx 78$), noise from the coil conductors (still the main sources of noise) is coupled mostly through parasitic capacitances (3) that are now enhanced by the large permittivity. In this situation much larger noise correlation was observed, indicating that the added capacitive coupling was considerably stronger than the residual inductive crosstalk. Capacitive coupling cannot be reduced by preamp decoupling.

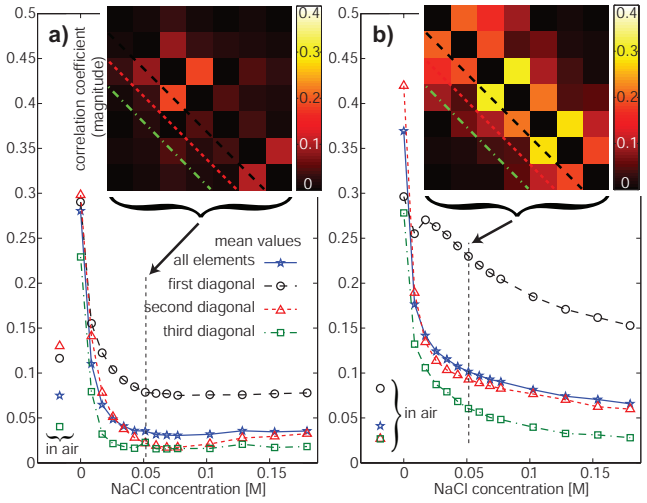

Figure 2: noise correlation coefficients (diagonals ≡ 1)

As NaCl is added the solution becomes an increasingly important source of noise (with physiological loading the unloaded-to-loaded Q ratio of 22 indicates dominant sample loading). Inductive crosstalk of the sample noise should be reflected by stronger noise correlation with the non-overlapping coils but the opposite was observed. This result is a clear indication that inductive coupling was successfully suppressed by the preamplifier and matching circuitry. For high conductivity in both overlap conditions a high noise correlation between adjacent coils was observed. This must be attributed to the coils' sensitivity to common noise sources in the phantom (4) (i.e., the coils see a mutual resistance (1)), and the measured correlations reflect the overlap of coil (electric) sensitivity profiles. For overlapping coils these common regions of noise sensitivity are naturally larger, resulting in larger noise correlation. The general decrease of noise correlation with increasing salinity is likely due to a combination of decreases in capacitive coupling as the dielectric medium becomes conductive, and to the "skin" effect in the phantom, leading to reduced overlap of the noise sensitivity profiles. For very large conductivities (2-4 times that of soft tissue) and non-overlapped coils, a possibly insignificant rise in correlation is observed whose origins are not yet understood.

Conclusion

In summary, these data demonstrate that in the presence of effective preamp decoupling, arranging coils without overlap leads to significant advantages in terms of noise correlation, in addition to those in terms of uniqueness of signal sensitivity profiles for image encoding using parallel imaging (5). This suggests that the optimal coil conductor placement should just cover the imaging region without overlap. Preamplifier decoupling ensures that inductive coupling among coils can be kept to negligible levels relative to its capacitive and resistive counterparts.

References: 1. Roemer PB et al. MRM 1990;16(2):192-225. 2. De Zanche N et al. NMR Biomed (in press) 3. Angelidis P et al. IEEE Trans. Ant. Prop. 1991;39(7):949-953. 4. Hayes CE et al. MRM 1990;16:181-191. 5. Weiger M et al. MRM 2001;45(3):495-504.