SNR Degradation in Receive Arrays Due to Preamplifier Noise Coupling and A Method for Mitigation

Graham Charles Wiggins[1], Ryan Brown[1], Bei Zhang[1], Marcus Vester[2], Stefan Popescu[2], Robert Rehner[2], and Daniel Sodickson[1]

[1]*The Bernard and Irene Schwartz Center for Biomedical Imaging, NYU Medical Center, New York, NY, United States,* [2]*Siemens Healthcare, Erlangen, Germany*

Introduction: Neighboring elements in a receive array can be decoupled by various means. However next nearest neighbors still exhibit substantial inductive coupling, which is usually mitigated through the use of preamplifier decoupling. It is commonly assumed that any remaining coupling effects can be removed by characterizing the coupling through measurement of the noise correlation matrix and application of optimum SNR reconstruction. However, various authors [1-3] have pointed out that noise generated in the preamplifier transistor projects back into the coil and couples to other elements in the array as a function of mutual impedance and preamplifier noise figure. This additional noise appears on the diagonal elements of the noise correlation matrix and therefore cannot be removed through optimum SNR combination. For most well-loaded array designs the effects are small. However, when body noise is not dominant, such as for small coil elements or at low field, the SNR degradation can be significant. Antenna theory suggests the strategy of broadband noise matching in the case of coupled antennas [4,5], in which a much higher impedance is presented to the preamp than would be required for optimum noise match. A detailed theoretical treatment of this strategy is provided in a separate abstract. We examine here the case of unloaded coils on an oil phantom to probe the nature of the effect and the efficacy of overmatching for recovering the lost SNR

Methods: Two rectangular coils 50mm on a side were placed 6mm above a large (24 x 24 x 19cm) peanut oil phantom. The coils were placed as though they were diagonal neighbors in an overlapped square coil array (Fig. 1), a configuration that results in very strong coupling. The experiments were conducted on a 3 Tesla Tim Trio scanner (Siemens Healthcare, Erlangen Germany). Each coil was individually matched (with the other coil detuned) with a combination of series and shunt capacitance so as to present various impedances to the preamp input, ranging from the standard optimal |s11|=0 (50Ω) to |s11|= 0.88. Cable lengths were adjusted to maintain preamp decoupling in each case. SNR was measured by acquiring two gradient echo scans in each case (TR/TE/Flip/slice/BW = 200ms/4.07ms/20°/3mm/300, matrix 256x256, FoV 300x300), one with RF excitation and a noise scan with no RF excitation. Raw data was saved and SNR for the optimum combination was calculated (6). For each case SNR was measured with one coil active and the other detuned, and then with both coils active, to determine the SNR drop due to the presence of the other coil both for the uncombined data from the original coil and for the combined SNR of the two coils.

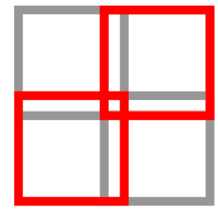

Figure 1: Surface coil elements (in red) were arranged as diagonal neighbors in a square lattice array

Results: With the standard 50 Ohm impedance presented to the preamps (for optimum noise match when coupling is zero or only one coil is active), individual coil SNR dropped to 28%, and SNR for the optimum combination dropped to 33% of the value obtained with only a single coil active (Figure 2). When the coils were deliberately overmatched so as to present |s11|= 0.88 to the preamps, the starting SNR for a single active coil was only 55% of the 50 Ohm matched case. However when the second coil was activated the SNR dropped only slightly to 93% and 95% for the uncombined coil and the combined SNR respectively. Compared to the single coil matched to 50 Ohms this represents a drop to 52% for the optimum combined SNR, a substantial improvement over the 33% achieved with the standard 50 Ohm match, but still not approaching the SNR we would hope to achieve based on the individual coil SNR.

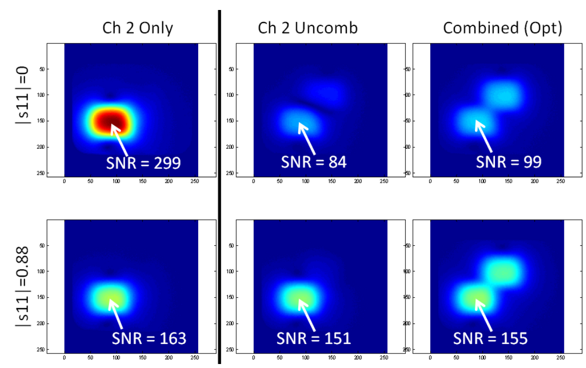

Figure 2: SNR in a coronal slice parallel to the coil plane and 1 cm deep in the phantom

Figure 3 shows a breakdown of the relative contribution of signal and noise to the final SNR in case of various different impedances being presented to the preamp. The SNR loss for the 50 Ohm matched case is primarily attributable to an increase in noise, consistent with noise being injected into the array from the other preamp. As the coil is increasingly overmatched, the difference in signal and noise when the second coil is active is reduced to almost nothing.

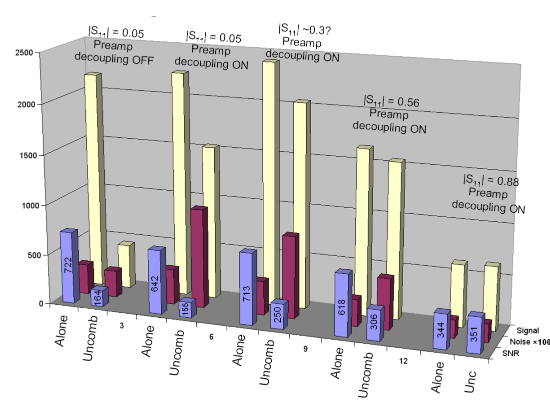

Figure 3: relative signal and noise contributions as a function of S_{11} reflection at the preamp inputs

Conclusions: When body noise is not dominant and coupling between coil elements is high, significant degradation in SNR can occur due to noise coupled from the preamps. These conditions will be approached in array designs which probe the limits of coil loading, such as extremely high element count arrays, low field arrays or very small arrays for animal imaging. This lost SNR can not be recovered through optimum SNR combination. Applying the strategy of broadband matching allows us to recover some but not all of the lost SNR. Most coil arrays will not exhibit the extreme SNR losses observed here, but losses that do occur may be mitigated through the strategy of overmatching.

[1] Reykowski. PhD thesis. 1996. [2] Findeklee, et al. ISMRM 2011 p1883. [3] Findeklee. IEEE Trans. Ant. and Prop., 59:2 (2011). [4] Lopez H. Wheeler's Antenna Design Legacy, http://www.arlassociates.net/May2007WheelerAntennaDesignLegacy.pdf.[5] Vester M. ISMRM 2012 6) Kellman P MRM 54:1439-1447.