A MONTE CARLO SIMULATION STUDY ON RECEIVER GAIN VARIATION OF LINEAR COMBINED MRI COIL ARRAY

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Introduction
Combiners/splitters have been widely used in MRI phased arrays for channel reduction and mode selection [1]. Unlike conventional uncombined MRI coil arrays where signals are weighted differently by the associated noise level in image reconstruction, combined MRI channels use RF switches and combiner circuits to merge received signals directly. Both the magnitude and phase of the signals require tuning prior combining. For coils with the combiner circuits integrated after the preamplifiers stage, the gain variations of these preamplifiers have significant impact on the performance of final combined signals. A Monte Carlo simulation aimed to help determine specifications for coil designers was tested based on real preamplifier data to investigate this effect.

Theory
An N-elements coil array has the signals modeled using complex-valued matrix form $S_{N\times 1}$. The associated noise is modeled as Gaussian with covariance matrix $\Sigma_{N\times N}$. Figure 1 shows the signal and noise propagation from coil element to combiner circuit. The gains of the individual preamplifiers are $Diag(A)$ and combiner coefficients matrix is $C_{M\times N}$. The final reconstructed image using root-sum-of-squares method is $S'_{RSS} = \sqrt{S'^{H}\Sigma'^{-1}S'}$.

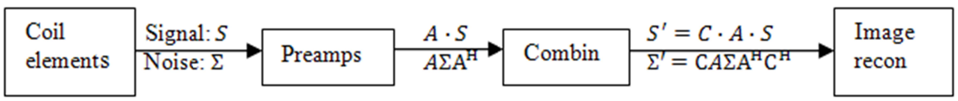

Figure 1

Simulation
A 4-channel coil array was simulated and the noise levels were set identical across four loop elements with mild noise correlation. A 4 to 4 combiner was used with coefficients $C = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 \end{bmatrix}$ to reduce noise correlation among combined channels. .

SNR of RSS reconstructed images are shown here for identical gains($Diag(A) = [1\ 1\ 1\ 1]$, figure 2a), best ($Diag(A) = [0.89\ 1.12\ 1.12\ 0.89]$, figure 2b) and worst ($Diag(A) = [1.12\ 0.89\ 0.89\ 1.12]$, figure 2c) cases for +/-1dB gain variation preamplifier gain combination. The ±1dB gain variation of preamplifiers can lead to 20% SNR difference in extreme cases.

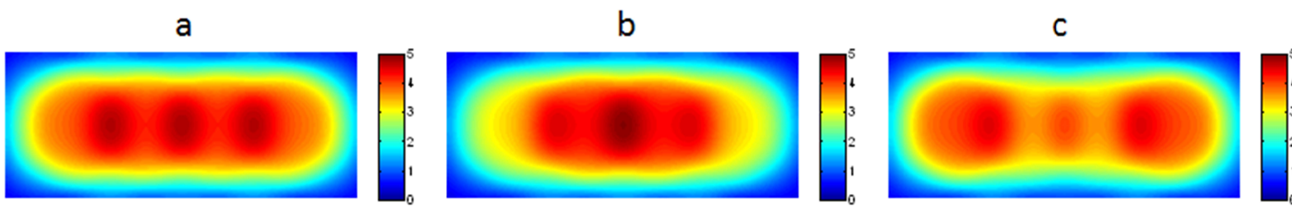

Figure 2

Experiment
30 samples of preamplifiers were measured by network analyzer and the average gain was 28 dB and standard deviation is 0.33dB. A prototype 4-channel coil with similar geometry to the simulation was scanned to obtain individual element signals (S) and noise covariance (Σ). A Monte Carlo simulation was set up to randomly draw gains of preamplifier from truncated Gaussian distribution above. For 10000 trials, the signals are combined using those preamp gains and the statistics of the combined SNRs are shown in table 1.

	Mean SNR	Standard deviation	Maximum SNR	Minimum SNR
From elements 1234	138.7	0	138.7	138.7
From channels 1234	139.1	1.7	141.3	117.4
From channels 12	128.2	1.5	136.5	118.3
From channels 13	150.0	1.9	152.7	127.1

Conclusion
Although the SNR degradation can be significant for extreme cases of preamplifier gains, the probability of the worst case is small based on the statistical distribution of practical preamp gain and consistent SNR can still be obtained using linear combined channels from coil array.

Reference
[1] U. Gotshal, et al., "The Linear EIGENCOIL," ISMRM Proc., p2389, 2004.