

The dependence of SNR on the number of independent coils

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Introduction

Phased array [1] and parallel imaging [2,3] have proven to be crucial developments to modern MR imaging equipment. The improved signal-to-noise ratio (SNR) and spatial selectivity that result from using arrays of large numbers of small receiver coils are driving the number of receiver channels higher than has ever been available, often at great cost. In this work we address the question of whether it is possible to have *too many* coils.

Theory

In order to assess the effect of the number of coils, N , used to cover a given field of view we take the approach of Wright et al. [4] whereby an area covered by a single surface coil is progressively divided into a patchwork of smaller and smaller coil areas (Fig. 1). The linear dimensions of the individual coil loops therefore scale as $1/\sqrt{N}$.

Array coils make use of low-noise preamplifiers to boost signal levels as well as to provide preamplifier decoupling [1]. In order to obtain the best preamplifier noise performance, each preamplifier must see an optimal source resistance, R_{opt} , at its input. Consequently we require that each coil will be connected to its corresponding low-noise preamplifier (LNA) through an impedance transformation network (shown schematically in Fig. 2 as an ideal transformer) whose voltage transformation ratio, k , will be such that the coil's output resistance, R_s , is transformed to R_{opt} :

$$k^2 R_s = R_{opt}.$$

Under this noise-matched condition, the noise level at the output of each preamplifier will be the same (assuming identical preamplifiers and temperatures) even if different coils require a different value for k .

Output signal, V_0 , is then dependent only on signal amplitude, V_s , and k , both of which depend on coil size. From the equations of the circuit of Fig. 2 we can derive the following proportionality for the output signal amplitude:

$$V_0 \propto \frac{V_s}{\sqrt{R_s}}.$$

If the signal originates from a source located some distance away from the coil array, the signal, V_s , induced in each coil will be proportional to the area of the coil, and hence proportional to $1/N$.

For sufficiently large values of N we can assume that the coils are small enough to neglect losses in the sample and consider R_s to be the ohmic resistance of each coil. If we allow the width of the copper trace to remain invariant upon scaling, the coil resistance will be proportional to $1/\sqrt{N}$, or remain constant if the width of the trace is also scaled. The output signal proportionality then reduces to $V_0 \propto N^{-0.75}$ or N^{-1} respectively.

If the signals are combined using a phased summation [4], e.g. in the case of MRS data, the total signal is N times that received up by a single coil. Conversely, the total noise increases as \sqrt{N} assuming uncorrelated noise. Correlations among noise components are likely to make the total noise increase even faster.

Results

Based on the above analysis the combined SNR from a deep source *decreases* as $N^{-0.25}$ or $N^{-0.5}$, depending on whether the width of the copper trace is scaled or kept constant with N . This perhaps counter-intuitive result can be understood by considering that while the total signal-receiving area is kept constant, increasing the amount of lossy copper and noisy preamplifiers does increase the total amount of noise in the combined data.

Conclusions

We have introduced realistic coil and preamplifier noise modeling to illustrate that in particular situations it may be better, from an SNR point of view, to use fewer coils rather than many. In practice this translates into a lower limit on coil size given the depth of the field of view. Parallel imaging techniques do take advantage of smaller coils but at depth similarities in the sensitivity profiles do not allow greater amounts of information to be acquired, while the combined noise increases because of additional lossy materials and non-ideal amplifiers. Significant improvements in the noise performance of coils and preamplifiers requires cryogenic conditions.

Further simulation work is in progress to incorporate more general signal combination schemes, coil arrangements, realistic electrodynamic effects (including losses in tissue) and non-ideal matching networks.

References

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