# Roemer reconstruction yields significant SNR gain over Sum-of-Squares @ 7T.

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## Introduction

Roemer et al.[1] provided a detailed description and comparison of different signal combinations for an array of multiple receiver coil: optimal SNR, magnitude SNR and Sum-of-Squares (SoS). Optimal and magnitude SNR reconstructions require the relative sensitivity of the coils and noise correlation matrix whereas the SoS calculates the square root of sum of squared signals ignoring the noise correlations. The SNR differences between these signal combination methods are generally thought to be modest. At low fields (signal frequency of 64 MHz) a theoretical SNR gain of no more than 10 % in case of the optimal SNR with respect to the SoS reconstruction has been shown theoretically as well as experimentally [1]. However, at high fields (e.g. 298 MHz @ 7T ) wave propagation effects arise which can degrade SNR in the images reconstructed with the SoS as the phases of receive fields (signal source) and electric fields (noise source) vary much stronger across the sample. Here we investigate the influence of the wave propagation effect on the SNR gain that can be obtained by optimally combining signals in the receive coil array at 7 Tesla.

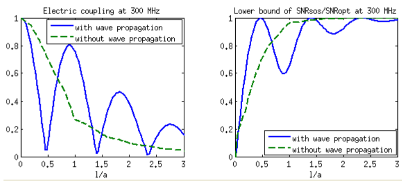


*Figure 1.Theoretical model predictions for electric coupling of two coils (left graph) and predicted possible SNR loss due to non-optimal SNR reconstruction (right graph) for different distances between coils with the wave propagation and without wave propagation factor taken into account.*

## Methods

A simple theoretical model to calculate electric couplings between two coils including wave propagation factor $e^{-j\vec{k}\cdot\vec{r}}$ was based on the following vector potential expression [2]:

$$\vec{A} = \frac{\mu_0}{4\pi}\int \frac{\mathrm{d}\vec{I}}{|\vec{r}-\vec{r'}|}\cdot e^{-j\vec{k}\cdot\vec{r}}, \text{ where } k^2 = \mu\epsilon\omega^2 + i\mu\sigma\omega.$$

By omitting the factor $e^{-j\vec{k}\cdot\vec{r}}$ which describes the wave propagation effect, we obtain a quasi-static model equivalent to the one used in Roemer's paper. The electric coupling coefficient was calculated in terms of vector potential:

$$k_{e12} = \frac{\int \vec{A_1}\cdot\vec{A_2}^{*}\mathrm{d}v}{\int|\vec{A_1}|^2\mathrm{d}v\int|\vec{A_2}|^2\mathrm{d}v}$$

All the numerical calculations and integrations were performed in Matlab (The Mathworks, Natwick, USA). The calculated geometry compromised two square coils (12x12 $cm^2$) located on the surface of the slab (120x120 $cm^2$, thickness 24 cm, $\varepsilon_r$ = 38, cond = 0.3 S/m). GRE images of a cylindrical body phantom (ø 50 cm, thickness 20 cm, human body equivalent electrical properties) were obtained with two comparable dual element receive coil array for 1.5 and 7 Tesla, respectively. At low field the body coil reference scan was performed to obtain individual coil receive sensitivities. At 7 T travelling wave MRI with the patch antenna [3] was utilized to get a reference scan [4]. In both cases images were obtained with optimal SNR (SENSE R=1) and SoS reconstruction techniques. Noise levels for both methods were obtained from the reconstructed dynamic noise scan (no RF, no gradients). Reconstructed images were divided by standard deviation of noise to get SNR maps. To compare the two reconstruction techniques in-vivo a healthy volunteer was placed in a 7T MR scanner and GRE images were obtained with the patch antenna for transmit and for local receive a home designed array of eight in-line overlapping loop coils was placed on the back of the volunteer (FFE 3D, TR/TE 17/4.5 ms, ACQ voxel 1/1/2 $mm^3$). The images were reconstructed with the SoS and optimal SNR methods.

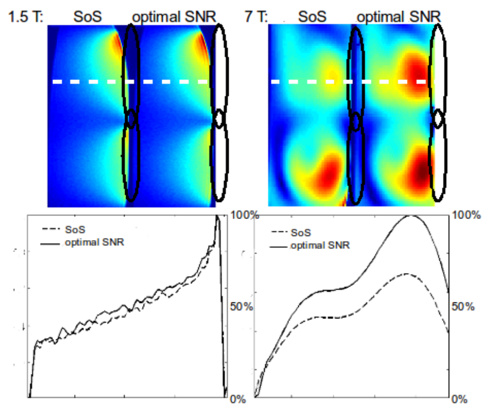


*Figure 2. Experimentally measured SNR maps in the phantom at 1.5 (left column) and 7Tesla (right column) for the square-root-of-sum-of-squares (left) and optimally reconstructed images (right). Location of coils is depicted by black ovals. Relative SNR profiles along the white dashed line for both reconstruction methods are plotted below.*

## Results and Discussion

The calculated electric coupling without the wave propagation gradually decreases with the distance between coils. This curve is very similar to the one presented in Roemer's paper for 60 MHz as no frequency dependence enters the quasi-static model (Fig. 1 dashed line). By taking the wave propagating factor into account the model predicts a strong fluctuation of the electric coupling with the distance between coils at 300 MHz (Fig.1 solid line). In case of the generally used coils overlap for inductive decoupling (l/a = 0.9) the electric coupling of coils at high field is large. Thus, the theoretical relative SNR gain with the optimally combined signals which is proportional to $\sqrt{1-k_{e12}^2}$ can reach 40% at high fields whereas at low fields for the same coil separation it is below 10% (Fig 1. right graph) Note that the model predicts that at certain separations coils are inherently electrically decoupled. At these separations SoS and optimal SNR should not differ naturally. In the MR experiment almost no difference between the optimal and the SoS reconstruction was observed at 1.5 T whereas at 7 T a considerable SNR increase (~30 %) for some image areas is achieved with the optimal SNR reconstruction (Fig. 2). In-vivo images also demonstrate significant quality improvement from optimal SNR reconstruction in voxels close to the coils as well as at the deeper locations (Fig. 3).

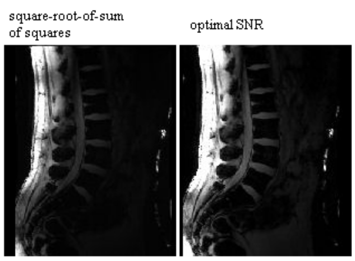


*Figure 3. Sagittal GRE MR images of lumbar spine obtained with the square root-sum-of-squares (left) and optimal (right) reconstruction techniques .Both images are depicted with the same window level.*

## Conclusions

We have demonstrated that, in contrast to general experience at low fields, at high fields the optimal SNR image reconstruction technique is beneficial as it can considerably increase image quality. To fully exploit the SNR potential of high field, one should perform optimal SNR signal combination.

## References

[1] Roemer P.B., et al. Mag Res Med (1990) 16; [2] C.A. Balanis, Antenna Theory 3rd edition, Wiley 2005; [3] D.O. Brunner et al., "Traveling-wave nuclear magnetic resonance", Nature 457; [4] A. Andreychenko et al., "An advantageous combination of travelling wave and local receive for spine MR imaging at 7T: local SAR reduction and SENSE reconstruction", 18th ISMRM, Stockholm 2010.