Minimum Norm Parallel Transmit Pulse Design

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Introduction:

One of the most promising technological developments of recent years is the extension of parallel receive imaging [1,2] towards signal excitation with independently operated transmit coils [3,4,5]. Similar to the receive case, parallel transmit exploits spatial variations in the excitation characteristics of a transmit array to increase the efficiency of the excitation process. Mathematically, this is described by incorporating the inhomogeneous excitation characteristics of a transmit array into Pauly's small tip-angle approximation [6].

In this work it is shown that spatial transmit sensitivity variations in combination with the small matrix sizes typically applied in 2D selective excitation (~32x32) can lead to a new artifact in the form of significant remaining aliasing in the desired excitation (/suppression) profile. In order to address this problem minimum norm principles known from parallel receive imaging [7] are translated towards parallel transmit excitation.

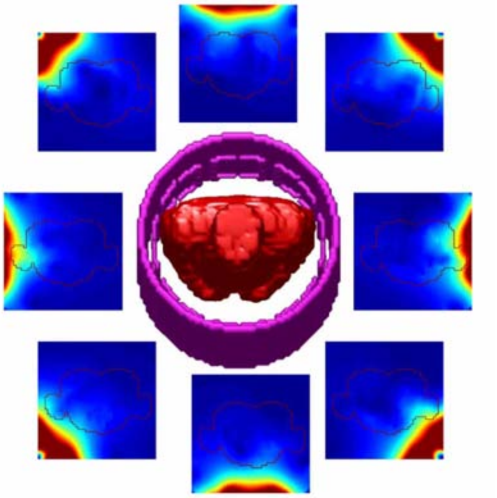

Fig1.: Simulation setup consisting of an 8-element whole body transmit array loaded with a human subject. Individual transmit sensitivities are shown for an axial plane within the human torso.

Methods:

Using Pauly's low-tip angle k-space formulation parallel transmit excitation can be formulated in a comprehensive matrix formulation as **m** = **T** * **b,** with the excitation matrix **T** defined as:

$$T_{\rho,\gamma\kappa} = s_\gamma(r_\rho)\exp(ik_\kappa r_{\rho,}) \qquad [1]$$

m the desired excitation profile, **b** a vector containing the individual coil's RF waveforms and $s_\gamma(\mathbf{r}_\rho)$ the transmit sensitivity of coil γ. This formulation also points out the analogy to parallel receive imaging, where a similar encoding matrix **E** describes the physical model for parallel receive signal acquisition [2].

The principal idea of minimum norm parallel transmit pulse design is to solve the inverse problem [Eq.1] for a spatially finer resolved excitation matrix **T**. Doing so, a more accurate excitation profile can be obtained via closer inspection of details of the excitation process. Analogous to the receive case [7], this becomes especially important when the coil sensitivity varies significantly across the dimension of a single voxel. The inverse problem of calculating the required RF waveforms **b**, which result into the desired excitation profile **m**, given the excitation matrix **T** [Eq.1]) has been solved using Bayesian inference theory [8].

Theoretical simulations and practical experiments have been performed using a 3 tesla, whole-body transmit array consisting of eight identical, rectangular coil elements (19x56cm^2) cylindrically arranged at a diameter of 61.4cm [9].

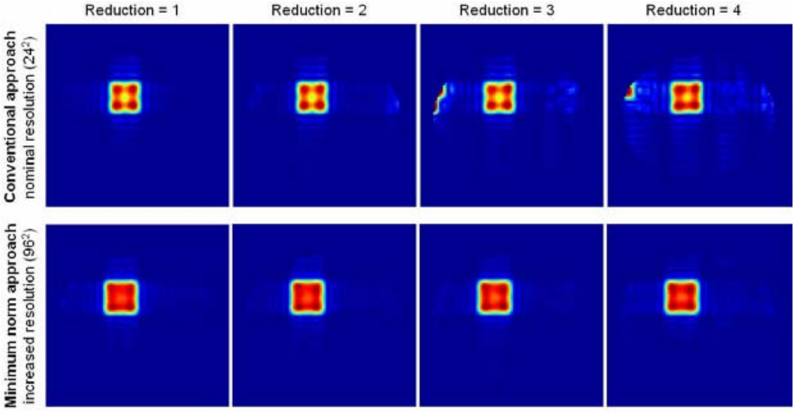

Fig2.: Simulation results demonstrating improved excitation profile definition obtained using the minimum norm parallel transmit SENSE pulse design approach.

Results and Discussion:

FDTD simulations have been performed for the whole-body, transmit array loaded with a human subject (Fig.1) assuming a FOV of 40^2 cm^2 and a nominal matrix size of 24^2. Figure 2 shows corresponding computer simulation results comparing excitation profiles obtained with the conventional approach and the minimum norm approach. In this example **T** has been resolved at four-fold increased spatial resolution. These results show that the conventional approach leads to significant aliasing contributions in particular at locations close to the surface of the object. The apparent insufficient suppression of aliasing artifacts is related to performing the unfolding operation at a too rough spatial resolution. However, this artifact can efficiently be addressed using the minimum norm approach with a spatially four-fold finer resolved excitation matrix **T**.

In addition to computer simulations, experimental phantom measurements have been performed using a dedicated 8-element whole-body transmit array connected to a synchronized 3T, multi-cabinet GE Signa Excite parallel transmit platform (GE Healthcare, Milwaukee, WI). Figure 3 shows parallel transmit selective excitation results obtained using a Cartesian echo-planar fly-back trajectory with a reduction factor of R = 2. With a nominal excitation k-space resolution of 32x32 this resulted in a RF pulse length of 14.6ms. For the measurements a 3D spoiled gradient echo sequence has been applied with a FOV of 20^{2}cm^2.

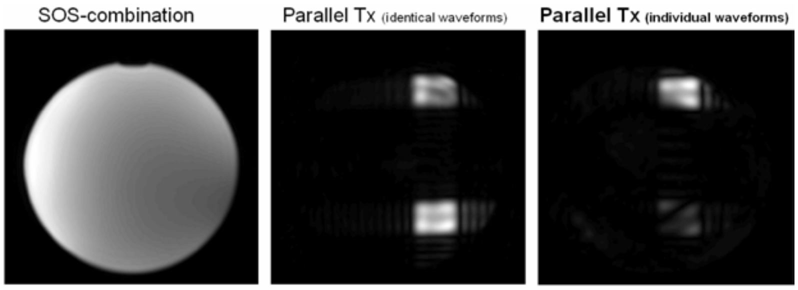

Fig3.: Parallel transmit selective excitation at 3T using an 8-element whole-body parallel transmit array: 32x32 Cartesian fly-back echo-planar trajectory using a reduction factor of R = 2.

References:

[1] Sodickson, et al, MRM 38: 591-603 (1997); [2] Pruessmann, et al, MRM 42: 952-962 (1999); [3] Katscher, et al, MRM 49: 144-150 (2002); [4] Zhu, et al, MRM 51: 775-784 (2004); [5] Grissom, et al, MRM 56: 620-629 (2006); [6] Pauly, et al, JMR 81: 42-56 (1989); [7] Sanchez-Gonzalez, MRM 55: 287-295 (2006); [8] Wiesinger, et al, ISMRM06: p.603; [9] Boskamp, et al, ISMRM07: submitted.

Acknowledgement: This project receives co-funding under the Bavarian research initiative "Leading Edge Medical Technology Programs.