An Image Domain Approach for the Design of RF Pulses in Transmit SENSE

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INTRODUCTION:

Transmit SENSE has recently been introduced by Katscher et al. (1) as a method of multidimensional selective excitation using multiple coils, each driven by an independent waveform. In a manner analogous to SENSE imaging, a reduced excitation k-space trajectory may be used to achieve a desired excitation pattern. In this work we introduce an image domain method for the design of RF pulses in Transmit SENSE. This method stands in contrast to the method in (1), which is formulated in the excitation k-space domain. It is shown that this approach produces RF pulses of similar quality to that in (1), but allows excitation error weighting, physically meaningful regularization, and compensation for main field inhomogeneity.

THEORY:

The proposed approach is an extension of the single-coil iterative RF design method proposed by Yip et al in (2). Assuming small tip angles, the excitation pattern resulting from multiple localized coils can be approximated by a linear, sensitivity-weighted combination of RF pulses:

$$m(\mathbf{x}) = i\gamma m_0 \sum_{r=1}^{R} S_r(\mathbf{x}) \int_0^T b_{1,r}(t) e^{i\gamma \mathbf{x}\cdot\mathbf{k}(t)} dt \qquad [1]$$

where R is the number of transmit coils, each with sensitivity pattern $S_r(\mathbf{x})$ and RF pulse $b_{1,r}(t)$. Discretizing time and space, we may write:

$$\mathbf{m} = \sum_{r=1}^{R} diag\{S_r(\mathbf{x}_i)\}\mathbf{A}\mathbf{b}_{1,r}(\mathbf{k}(t_j)) \qquad [2]$$

where $a_{ij} = i\gamma \mathbf{m}_0 \Delta t e^{i\mathbf{x}_i\cdot\mathbf{k}(t_j)}$. The summation in [2] may then be replaced by a concatenation of the matrices and vectors, resulting in $\mathbf{m}=\mathbf{A}_{full}\mathbf{b}_{full}$. Given a desired pattern $\mathbf{m}_{des}$, the RF pulses can be designed via:

$$\hat{\mathbf{b}}_{full} = \arg\min_{\mathbf{b}_{full}} \left\{ \left\| \mathbf{A}_{full}\mathbf{b}_{full} - \mathbf{m}_{des} \right\|_{\mathbf{W}}^2 + \lambda^2 \left\| \mathbf{b}_{full} \right\|^2 \right\} \qquad [4]$$

where λ is a regularization parameter. Regularization may be used to control integrated RF power, waveform smoothness, and peak RF power. The minimization problem can be solved by pseudoinverse or by the Conjugate Gradient method, in a manner similar to the single-coil pulse design method proposed by Yip et al. This design approach allows for excitation error weighting within the field of view via the matrix **W**, which may specify a region of interest (ROI). Furthermore, a B_0 field map may be incorporated into the **A** matrices by including an exponential term representing the phase accumulated during excitation due to magnetic field inhomogeneities, $a_{ij} = i\gamma \mathbf{m}_0 \Delta t e^{i\gamma\Delta B_0(\mathbf{x}_i)(t_j - T)} e^{i\mathbf{x}_i\cdot\mathbf{k}(t_j)}$.

SIMULATION AND EXPERIMENTAL RESULTS:

We performed Bloch equation simulations to test our approach to Transmit SENSE RF pulse design and to compare it with the approach presented in (1). Fig. 2a shows the desired excitation pattern $\mathbf{m}_{des}$ chosen, which was defined on a 32x32 matrix with a FOV of 20cm. The applied k-space trajectory was of a spiral form and was radially undersampled by 4 times, to yield an excitation FOV of 5cm. Sensitivity profiles were determined experimentally. Equation [4] was solved by pseudoinverse. Figs. 1b and c show the effects of the inclusion of magnetic field inhomogeneities into the simulation, and the corrected magnetization pattern produced using our method. Table 1 contains a comparison of normalized excitation errors in the presence of main field inhomogeneity resulting from pulses designed with our method and pulses designed using the method in (1). We performed an experiment using the method described in (3) with the same excitation parameters and sensitivity profiles described above. Figs. 2b-e show the individual excitation patterns resulting from each coil's pulse, and Fig. 2f shows the complex sum image of these patterns.

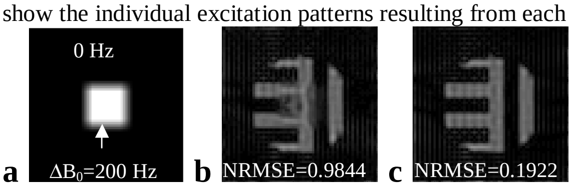

Figure 1: a: Main field inhomogeneity map. **b:** Excitation pattern resulting from uncorrected pulses. **c:** Excitation pattern resulting from corrected pulses.

	ΔB_0=0Hz	ΔB_0=100Hz	ΔB_0=200Hz
Katscher (1)	0.0801	0.5309	0.8893
Proposed	0.0792	0.1299	0.2196
Proposed w/ROI	0.0451	0.1052	0.1945

Table 1: Normalized excitation error resulting from excitation in the presence of main field inhomogeneity.

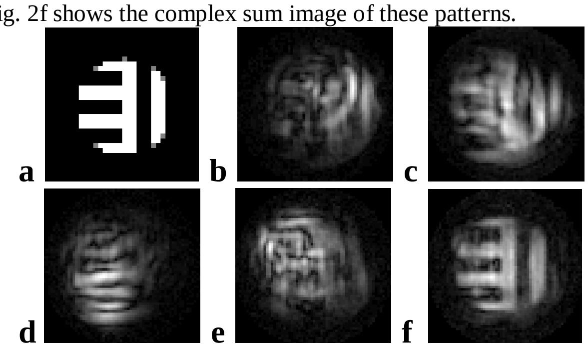

Figure 2: a: Desired excitation pattern $\mathbf{m}_{des}$. **b,c,d,e:** Individual excitation patterns. **f:** Sum of individual patterns.

DISCUSSION:

We have presented an image domain method for the design of RF pulses in Transmit SENSE and have verified it in experiment. We have shown that it results in pulses with similar excitation error as the previously introduced method (1), while allowing for physically meaningful regularization, compensation for main field inhomogeneities, and excitation error weighting.

REFERENCES:

[1] U. Katscher et al. Transmit SENSE. Magn Reson Med 2003;49:144-150. [2] CY Yip et al. In: Proceedings of the 12th Annual Meeting of ISMRM, Kyoto, 2004. p 188 [3] V.A. Stenger et al. In: Proceedings of the 2nd International Workshop on Parallel MRI, Zurich, 2004. p. 94

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