A New Method 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 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 a new method for the design of RF pulses for Transmit SENSE. It is shown that this approach produces RF pulses of similar quality to that in (1), but allows specification of regions of interest (ROI's), can compensate for magnetic field inhomogeneity, and has reduced need for regularization.

THEORY:

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 the time and spatial coordinates, we may write:

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

where $a_{ij} = i\gamma \mathbf{m}_0 \Delta t e^{-i\gamma \mathbf{x}_i \cdot \mathbf{k}(t_j)}$. The summation in [2] may then be replaced by a concatenation of the matrices and vectors, resulting in:

$$\mathbf{m} = \mathbf{A}_{full}\mathbf{b}_{full} \qquad [3]$$

Given a desired pattern $\mathbf{m}_{des}$, the RF pulses can be designed via:

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

where λ is a regularization parameter. 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. in (2). This design approach allows for the specification of ROI's within the field of view by excluding the points outside the ROI from $\mathbf{m}_{des}$. 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:

$$a_{ij} = i\gamma \mathbf{m}_0 \Delta t e^{-i\gamma \Delta B_0(\mathbf{x}_i)(t_j - T)} e^{-i\gamma \mathbf{x}_i \cdot \mathbf{k}(t_j)}. \qquad [5]$$

SIMULATIONS:

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. 1a 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 2 times, to yield an excitation FOV of 10cm. Equation [4] was solved by pseudoinverse. Fig. 1b and 1c show the two coil sensitivity profiles S_r used, which were of a 2D Gaussian shape, multiplied by a Hanning window to suppress edge effects. Fig. 1d and 1e show the resulting excitation patterns using our method and the method in (1), respectively. Table 1 contains a comparison of the minimal levels of excitation error (Normalized RMS Error), the corresponding integrated RF power, and the amount of regularization required to acheive this error. Due to interpolation and a larger regularization parameter λ, we found it necessary to multiply pulses designed using the method in (1) by a scaling factor (~10) to achieve the desired tip angle. Fig. 3a and b show the effects of the inclusion of magnetic field inhomogeneities into the simulation, and the corrected magnetization pattern produced using our method.

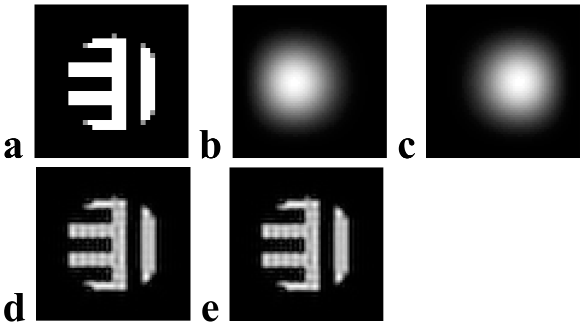

Figure 1: a: Desired excitation pattern $\mathbf{m}_{des}(\mathbf{x}_i)$. **b ,c:** Transmit coil sensitivities $S_r(\mathbf{x}_i)$. Resulting excitation patterns using **d:** our method and **e:** the method in (1).

Table 1: Summary of pulse designs from Figure 1.

Design Method	NRMSE	λ	RF power (a.u.)
Katscher (1)	0.0547	1	71.3365
Proposed method	0.0543	0.0032	73.7699

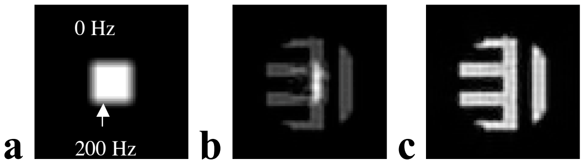

Figure 3: a: Main field inhomogeneity map. **b:** Excitation pattern resulting from uncorrected pulses. **c:** Excitation pattern resulting from corrected pulses.

DISCUSSION:

We have presented a new method for the design of RF pulses in Transmit SENSE and have tested it in simulation. We have shown that it results in pulses with similar excitation error and power as the previously introduced method (1) while requiring less regularization and achieving the desired tip angle without normalization. The new method also allows for the specification of ROI's and compensation for magnetic field inhomogeneities.

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