An Algorithm for Fast Parallel Excitation Pulse Design

Shuo Feng[1] and Jim X. Ji[1]

[1]Electrical and Computer Engineering, Texas A&M University, College Station, Texas, United States

Target audience: high field MRI engineers and users; engineers interested in parallel excitation and RF pulse design

Purpose:

Parallel excitation [1] is useful in addressing challenges in the high field MRI, such as transmit field inhomogeneity and the elevated SAR. Existing 3D pulse designs mainly adopt the spoke excitation trajectory and fix the pulse waveform to be Sinc functions before optimizing the weights. As such, they often do not take full advantage of the parallel excitation and/or other excitation trajectories [2, 3]. However, pulse design with non-Sinc waveforms can be extremely time consuming, especially for 3D pulse design in practical applications. In this work, we propose a fast pulse design algorithm that explores the sparsity in target pattern and reduces the size of the pulse design equation.

Method:

Parallel RF pulses designs using the spatial domain method is based on a small-tip-angle approximation; the design equation is given by

$$M(\vec{x}) = i\gamma M_o \sum_l s_l(\vec{x}) \int_0^T B_{1,l}(t) e^{-i\cdot\vec{x}\cdot\vec{k}(t,T)} dt \qquad (1)$$

where the notations follow those in [1]. For sophisticated excitation trajectories such as spirals or non-uniform spokes, Eq. (1) leads to a large linear system and requires significant computing time to solve. In several applications such as in B_1 or B_0 field inhomogeneity correction at high fields, the pattern is relatively smooth. In the proposed method, we perform a sparse transform (in this case, a Fourier transform) on both sides of Eq. (1) to get.

$$\int M(\vec{x}) e^{-i\cdot\vec{x}\cdot\vec{k}_s} \mathrm{d}\vec{x} = \int \left(i\gamma M_o \sum_l s_l(\vec{x}) \int_0^T B_1(t) e^{-i\cdot\vec{x}\cdot\vec{k}(t,T)} dt \right) e^{-i\cdot\vec{x}\cdot\vec{k}_s} \mathrm{d}\vec{x} \qquad (2)$$

where $\overrightarrow{k_s}$ is the spatial frequency in the Fourier transform. Eq. (2) can be further simplified to

$$\tilde{M}(\vec{k}_s) = i\gamma M_o \int_0^T B_1(t) \sum_l \tilde{S}_l\left(\vec{k}_s + \vec{k}(t,T)\right) dt \qquad (3)$$

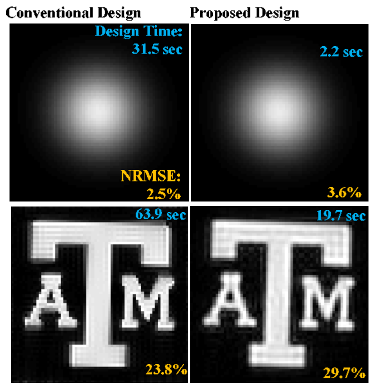

Fig.1 2D selective excitation.

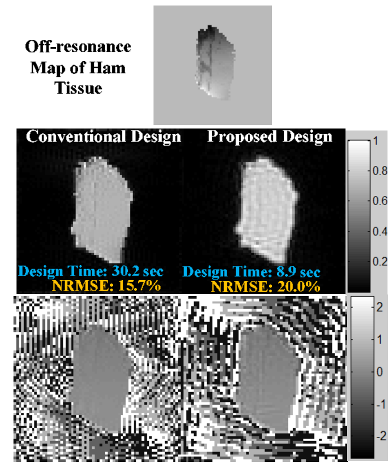

Fig.2 Off-resonance correction: the excited magnitude (2nd row) phase errors (3rd row)

where $\tilde{M}$ and $\tilde{S}_l$ are spectrums of the target pattern and the transmit map of individual coil. In Eq. (3) only the rows corresponding to low frequencies and high amplitude components of $\tilde{M}$ are significant. By keeping only these sparse components, the rank and thus computing time of Eq. (3) can be reduced significantly. Note that the right side of Eq. (3) must be transformed and truncated accordingly. The reduced equations can be solved using a conjugate gradient method to yield the desirable RF pulse. Gradient waveforms are derived from the excitation trajectory directly.

The proposed method is evaluated via simulations in three scenarios. First, it is used to design parallel excitation pulses to achieve patterns of different smoothness; Second, pulses are designed for off-resonance correction in a real tissue; Finally, 3D selective parallel pulses are designed for transmit B_1 field correction in a slab In the simulations, an 8 channel linear transmit array is used. For the first two experiments, 2D spiral is used; FOX is set to 20cm on a 64x64 grid. For the last 3D experiment, a 5-spoke trajectory is specified. Truncation ratios from 1 to 20 were tested. Both computation time and excitation errors are evaluated. Bloch simulator is used to generate excitation patterns in all experiments. Normalized root mean square error (NRMSE) was used to gauge the numerical excitation errors.

Results:

Results of the 2D experiment are shown in Fig.1. For the smooth pattern on the top, the new method can achieve about 15 times speedup with only slightly increased error. A factor of three speedup can be achieved even for the more complicated pattern on the bottom. The off-resonance correction results are shown in Fig. 2. The off-resonance is corrected in both methods since the phase error in tissue is almost zero. The proposed method is about 4 times faster in this example. The 3D pulse design result using the proposed method is shown in Fig.3. When truncation ratio equals to 1, the proposed method is equivalent to the conventional method. As the truncation ratio increases, the design speed is improves dramatically while the excitation error only increases by about 1%.

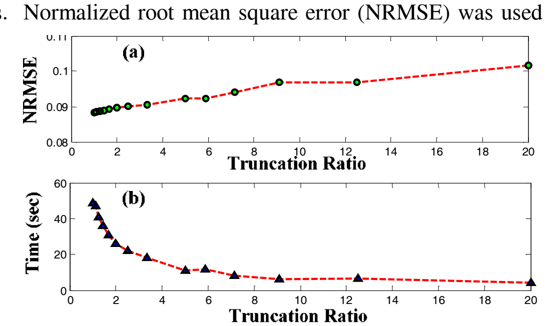

Fig.3 Excitation error and computation time for 3D pulse design using the proposed design at multiple truncation ratios

Conclusion and Discussion:

The proposed method employs the sparsity of the target pattern in the pulse design. Up to 10 fold design acceleration is feasible in 3D selective parallel excitation examples tested. The method can significantly accelerate parallel excitation pulse design, which makes it more practical to use the technique in real applications where imaging time is constrained.

Reference:

[1] W. Grissom, *et al.*, "Spatial domain method for the design of RF pulses in multicoil parallel excitation," *MRM* 2006:(56) 620
[2] S. Tingting, *et al.*, "Advanced Three-Dimensional Tailored RF Pulse Design in Volume Selective Parallel Excitation," *TMI* 2012 (31): 997
[3] F. Shuo and J. Ji, "3D selective pulse design with variable spoke trajectories for parallel excitation," *EMBC 2011,* 284