Nuts & Bolts of Advanced Imaging: Parallel Transmit Pulse Design

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Highlights

- Small- and large-tip-angle parallel transmit pulse design are both based on the inversion of a forward model for excitation, but require different solution strategies.
- Unlike conventional multidimensional pulse design, B_1^+ magnitude and relative phase maps for each transmit coil are required for parallel transmit pulse design.
- For certain pulse types as spokes, the design problem can be dramatically simplified and accelerated.
- For in-vivo applications, RF power and SAR evaluation and control is crucial.

Target Audience: Students and researchers interested in applications of multidimensional parallel excitation, and in the development of parallel transmit RF pulse design algorithms.

Outcome & Objectives: From the theory lecture of the course, participants will learn about approaches to small-tip-angle spiral and spokes parallel transmit pulse design. Example code for both cases, as well as the slides of the theory talk in pdf format, can be downloaded from: `http://goo.gl/wTriI`. In the interactive hands-on portion of the course, participants will explore the small-tip-angle code, extend it to design large-tip-angle pulses, and evaluate the SAR of the resulting pulses.

Purpose: Magnetic resonance imaging (MRI) at high field strengths higher promises to enhance clinical diagnosis and enable new medical discoveries. However, at high field inhomogeneous transmit RF (B_1^+) fields cause spatially-varying image contrast and even complete loss of signal, severe B_0 inhomogeneity causes signal loss near regions of high susceptibility differences, and increased specific absorption rate (SAR) poses a serious safety risk. Parallel transmission has the potential to address these problems, directly and indirectly, by providing an additional spatial encoding mechanism (the multiple channels and coils of a parallel transmit system) that enhances one's ability to tailor excitation pulses to specific patients and anatomy. In this course students will learn how to take advantage of those new degrees of freedom in RF pulse design.

Methods: Small-tip-angle multidimensional designs are simplified by linearity of the spatial excitation pattern in the RF pulses, which enables pulse design by matrix inverse or iterative methods. Pulse design requires the co-design of an excitation k-space trajectory, which is based on considerations of pulse duration, excitation FOV, and the required sharpness of the excitation pattern. The B_1^+ patterns of each coil must be included in the forward excitation model, and are generally measured in each subject prior to pulse design. Target excitation patterns and excitation error weighting can be constructed to approximately achieve target flip angle ripple levels. SAR evaluation is straightforward for a given set of pulses, but ideally SAR is constrained during pulse design. Large-tip-angle parallel transmit pulse design is generally based on extensions of optimal control to the multi-channel case. Selection of an excitation trajectory for a large-tip-angle pulse in some cases requires additional considerations.

Discussion and Conclusion: Parallel transmit pulse design is a rich problem space, with significant need both for better general-purpose pulse design algorithms, and for the application and adaptation of existing algorithms to specific applications. This course will be a springboard to help participants get started in developing their own parallel transmit pulse design algorithms.

Parallel Transmit Pulse Design References:

D O Brunner and K P Pruessmann. Optimal design of multiple-channel RF pulses under strict power and SAR constraints. *Magn Reson Med*, 63(5):1280–1291, 2010.

M A Cloos, N Boulant, M Luong, G Ferrand, E Giacomini, D Le Bihan, and A Amadon. k_T-Points: Short three-dimensional tailored RF pulses for flip-angle homogenization over an extended volume. *Magn Reson Med*, 67:72–80, 2011.

W A Grissom, C Y Yip, Z Zhang, V A Stenger, J A Fessler, and D C Noll. Spatial domain method for the design of RF pulses in multicoil parallel excitation. *Magn Reson Med*, 56(3):620–9, Sep 2006.

W A Grissom, C Y Yip, S M Wright, J A Fessler, and D C Noll. Additive angle method for fast large-tip-angle RF pulse design in parallel excitation. *Magn Reson Med*, 59(4):779–787, 2008.

W A Grissom, D Xu, A B Kerr, J A Fessler, and D C Noll. Fast large-tip-angle multidimensional and parallel RF pulse design in MRI. *IEEE Trans Med Imaging*, 28(10):1548–1559, Oct. 2009.

W A Grissom, M M Khalighi, L I Sacolick, B K Rutt, and M W Vogel. Small-tip-angle spokes pulse design using interleaved greedy and local optimization methods. *Magn Reson Med*, 68:1553–62, 2012.

U Katscher, P Börnert, C Leussler, and J S van den Brink. Transmit SENSE. *Magn Reson Med*, 49(1):144–150, Jan 2003.

R Lattanzi, D K Sodickson, A K Grant, and Y Zhu. Electrodynamic constraints on homogeneity and radiofrequency power deposition in multiple coil excitations. *Magn Reson Med*, 61(2):315–334, 2009.

C Ma, D Xu, K F King, and Z-P Liang. Joint design of spoke trajectories and RF pulses for parallel excitation. *Magn Reson Med*, 65(4):973–985, 2011.

S Saekho, C Y Yip, D C Noll, F E Boada, and V A Stenger. Fast-kz three-dimensional tailored radiofrequency pulse for reduced B1 inhomogeneity. *Magn Reson Med*, 55(4):719–724, Apr 2006.

K Setsompop, L L Wald, V Alagappan, B Gagoski, F Hebrank, U Fontius, F Schmitt, and E Adalsteinsson. Parallel RF transmission with eight channels at 3 Tesla. *Magn Reson Med*, 56(5):1163–1171, Nov 2006.

K Setsompop, V Alagappan, B Gagoski, T Witzel, J Polimeni, A Potthast, F Hebrank, U Fontius, F Schmitt, LL Wald, and E Adalsteinsson. Slice-selective RF pulses for in vivo B_1+ inhomogeneity mitigation at 7 Tesla using parallel RF excitation with a 16-element coil. *Magn Reson Med*, 60(6):1422–1432, 2008.

K Setsompop, L L Wald, V Alagappan, B A Gagoski, and E Adalsteinsson. Magnitude least squares optimization for parallel radio frequency excitation design demonstrated at 7 Tesla with eight channels. *Magn Reson Med*, 59(4):908–915, 2008.

K Setsompop, V Alagappan, B A Gagoski, A Potthast, F Hebrank, U Fontius, F Schmitt, L L Wald, and E Adalsteinsson. Broadband slab selection with b_1^+ mitigation at 7T via parallel spectral-spatial excitation. *Magn Reson Med*, 61:493–500, 2009.

D Xu, K F King, Y Zhu, G C McKinnon, and Z P Liang. A noniterative method to design large-tip-angle multidimensional spatially-selective radio frequency pulses for parallel transmission. *Magn Reson Med*, 58(2):326–334, Jul 2007.

D Xu, K F King, Y Zhu, G C McKinnon, and Z-P Liang. Designing multichannel, multidimensional, arbitrary flip angle RF pulses using an optimal control approach. *Magn Reson Med*, 59(3):547–560, 2008.

A C Zelinski, L L Wald, K Setsompop, V K Goyal, and E Adalsteinsson. Sparsity-enforced slice-selective MRI RF excitation pulse design. *IEEE Trans Med Imaging*, 27(9):1213–1229, 2008.

Z Zhang, C Y Yip, W Grissom, D C Noll, F E Boada, and V A Stenger. Reduction of transmitter B1 inhomogeneity with transmit SENSE slice-select pulses. *Magn Reson Med*, 57(5):842–847, May 2007.

Y Zhu. Parallel excitation with an array of transmit coils. *Magn Reson Med*, 51(4):775–784, Apr 2004.