Successful 2-Spoke pTX RF Pulse excitation using a single-channel transmit 7T console retrofitted with a 16-channel B1 Shimming unit

Sebastian Schmitter[1], Xiaoping Wu[1], Edward John Auerbach[1], Lance DelaBarre[1], Gregor Adriany[1], Kamil Ugurbil[1], and Pierre-Francois Van de Moortele[1]
[1]*Center for Magnetic Resonance Research, University of Minnesota, Minneapolis, MN, United States*

INTRODUCTION. Ultra-high field (UHF; ≥7Tesla) MRI can provide higher SNR, better parallel imaging performance and often stronger contrast compared to lower fields, at the cost however of large transmit B1 (B1+) heterogeneity leading to non-uniform contrast. Spectacular improvements occurred since the development of multi-transmit coils and, subsequently, parallel transmission (pTX) technology. Initial implementations ('A') of B1 shim consisted of retrofitting a standard console with minimal hardware, at minimal cost: a large RF amplifier (RFA) output went in a *N*-channel splitter-combiner, feeding *N* RF coil elements; various cable lengths yielded channel-specific phases for B1 shim. Unfortunately, not many high field applications are satisfied with one B1 shim set, and B1 phases are awkward to set on high power end. In parallel, new pTX pulse designs ("Transmit SENSE") were proposed [1,2], where gradient waveforms are combined with *N* channel-specific RF pulse shapes sent by *N* synthesizers, feeding *N* RFAs, delivering multi-dimensional shaped excitation patterns with short pulse durations. Hardware costs for this 'FullPTX' option, are dramatically more expensive and, although FullPTX does offer uniquely versatile RF solutions, only few centers can afford this cost. A very popular middle-cost retrofitting solution, ('B'), based on a single channel Tx console, includes *N* RF amplifiers with channel-wise phase/amplitude modulation exercised on the low-volt input by a remotely controlled board. B1 shim solutions are easily switched between scans; more advanced B1 shim settings are cycled between different RF pulses of a sequence [3], expanding the scope of B1 shim applications.

A crucial step is the advent of *N-spoke RF pTX pulses* [4] with a 1D selective RF pulse shape plaid two or more times, with different B1 shim sets, with short gradient blips plaid in the between; this approach dramatically improves excitation homogeneity (slice- or slab-wise) while relaxing power constraints [4-6]. So far, however, these successes have only been shown with FullPTX systems. In this work we investigate the possibility of implementing *N*-spoke RF pulses using a much cheaper setting 'B', which could vastly expand pTX applications.

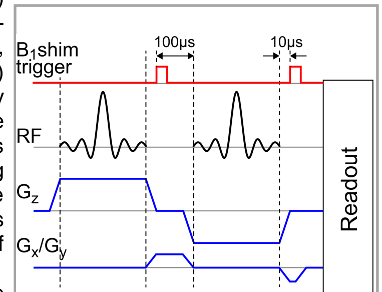

Fig.1: *Excitation scheme for the 2-spoke RF pulses using the B1+ shimming system. The shim unit is switched by a trigger signal 10µs after and 100µs before the next RF pulse.*

PRINCIPLE. Safely switching B1 shim settings between 2 spokes requires a) short switching time, b) clean circuitry (no switching noise), c) proper T/R switch up/down timing. Slice- or Slab-selective *N*-spoke RF pulses, typically include at least a few tens of µs between pulses. However, non-slice-selective kT-pulses [7] have shorter sub-pulses and intervals, requiring careful testing to determine time range of operation. **Application**. We have demonstrated with FullPTX the superiority of 2-Spoke pulses versus B1 shim in cerebral TOF and cardiac imaging at 7T [5,6]; we aim to reproduce these results on a system equipped with both setting 'B' and FullPTX. .

METHODS. Imaging was performed on a whole body 7T (Siemens, Erlangen, Germany) using a 16 channel B1+ phase/gain control unit (PGCU) (CPC, Hauppauge, USA) with a 16 channel transceiver head coil [8]. 2 healthy volunteers were imaged after obtaining consent. A TOF GRE sequence was modified as in Fig.1: 10us after each spoke a TTL signal triggers the PGCU to switch to the next B1 shim set. Although PGCU specifications read 5µs for B1+ switch time, a conservative pause of 100µs was inserted after the switch during which in-plane encoding blips (k_x-,k_y) are applied. We imaged slab-selective TOF angiography targeting the cerebral arteries and slice-selective cardiac MRI. For both, after B_0 mapping, fast multi-channel B_1+ calibration was performed [9] (TOF: 3 calibration slices, cardiac: one slice). ECG triggered Cardiac B_1 & B_0 maps were acquired under breath-hold. 2-spoke RF pulses were computed in Matlab (magnitude least squares optimization [10]) optimizing FA simultaneously on the 3 calibrations slices (1 slice for cardiac). Each spoke was 900µs long (total pulse duration: 2ms), bandwidth-time product was 10 (TOF) or 4 (cardiac).k_x, k_y gradient blip moments are loaded in the sequence while a table of complex B1shim values for 2-spokes and 16 channels is loaded in the PGCU. Acquisition parameters for TOF: TR/TE=20ms/3.1ms, nominal flip angle (FA) = 20°, $(0.5mm)^3$ resolution, 40mm slab thickness, 20% oversampling, Grappa=2, axial orientation, and for Cardiac: TR/TE = 5.5ms/1.95ms , nom. FA = 5°/10° (4-chamber/axial view), resolution = 2.1x2.1x5mm, Grappa=2, orientation: axial and pseudo-4-chamber. Acquisition made during 360ms in diastole. 2-spoke TOF was compared to CP mode excitation [11] with same pulse duration matching FA at the brain center. 2-spoke cardiac MRI was compared to initial/standard phase setting with same RF pulse duration. Absolute FAs (shown in Fig 2 and 3) were estimated by comparison with other studies.

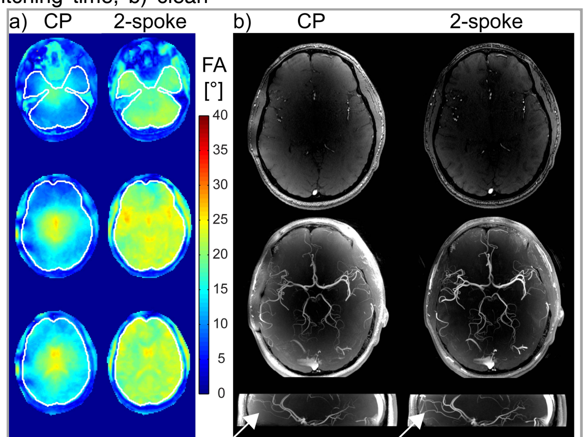

Fig.2: a) *Bloch simulations performed on 3 calibration slices across the TOF slab for RF pulses applied in CP mode and for 2-spoke excitation.* ***b)*** *single slice TOF image and MIP angiogram in axial and sagittal view.*

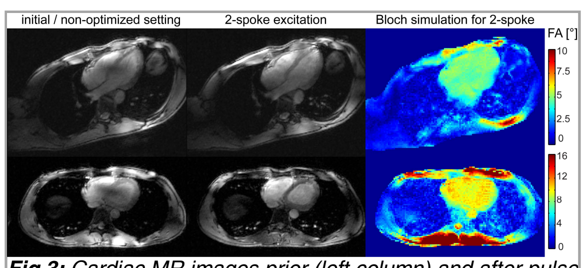

Fig.3: *Cardiac MR images prior (left column) and after pulse optimization using 2-spoke RF pulses. The right column shows Bloch simulations according to the middle column.*

RESULTS/DISCUSSION. Simulations (CP mode and 2-spoke excitation) are shown (Fig 2a) for the 3 calibration slabs. The coefficient of variation (CV=std/mean) of FA was reduced from 30.0% to 11.1%. Fig.2b shows the corresponding TOF images on an axial slice as well as maximum intensity projections (MIP) in axial and sagittal view. Gain in contrast is seen in brain periphery, especially in sagittal MIP view (see arrow). This is consistent with our pTX results [5]. Fig.3a shows cardiac images obtained with initial (non-optimized) B1 setting, equal RF amplitude, for all channels. With 2-spoke excitation, homogeneous contrast can be appreciated (images NOT corrected for receive profile), as reflected by the Bloch simulation shown in the right column. Using 2 spokes inhomogeneity (CV) was reduced in the heart from 23.2% to 8.2% (4-chamber view) and 34.3% to 10.0% (axial view) compared to the initial non-optimized setting.

CONCLUSION. We demonstrate that 2-spoke RF pulses can be applied with a single channel console retrofitted a la 'B'. Brain and cardiac results reproduced our FullPTX results. Given the considerable success of N-spoke RF pulses and the relative simplicity of their use, being able to use them in a configuration much cheaper than FullPTx systems may help spreading faster the use of pTX in biomedical applications. **ACKNOWLEDGMENTS**: P41 EB015894, S10 RR026783, KECK Foundation. **REFERENCES** [1] Katscher MRM 49:144 [2] Zhu MRM 51:775 [3] Metzger MRM 69:114, [4] Setsompop MRM 60:1422, [5] Schmitter Investig. Radiol. In press, [6] Schmitter MRM 70:1210 [7] Cloos MRM 67:72 [8] Adriany, MRM 59:590 [9] Van de Moortele, ISMRM 2009:367 [10] Setsompop MRM 59:908 [11] Schmitter ISMRM 2012:3472