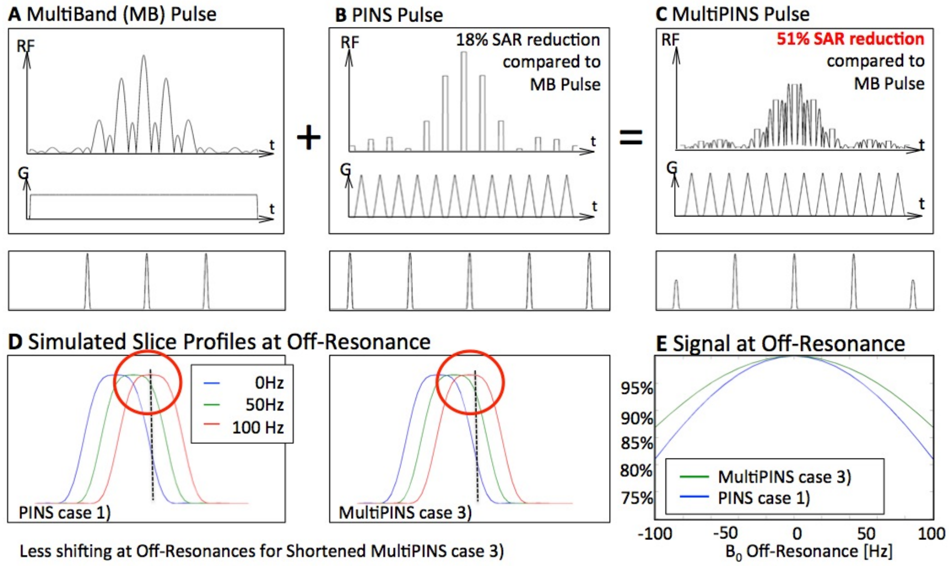
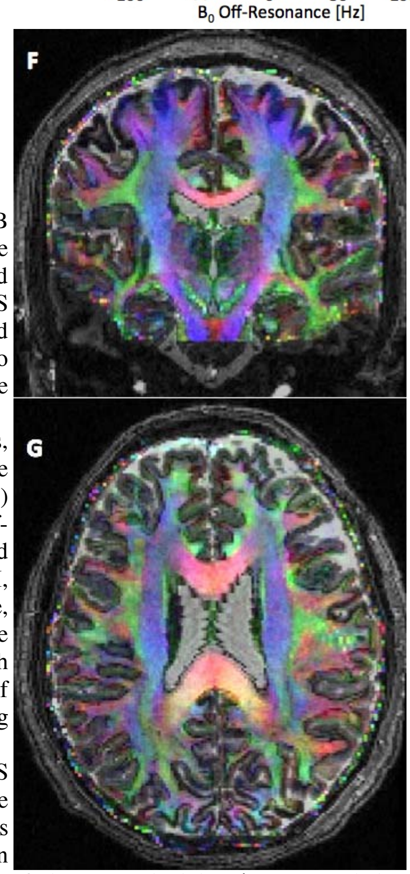
MultiPINS: PINS + MultiBand hybrid RF pulse with reduced SAR for SMS Imaging at Ultra High Field Strength

Cornelius Eichner[1,2], Robert Turner[2], Lawrence L Wald[1], and Kawin Setsompop[1]

[1]*Martinos Center for Biomedical Imaging, Massachusetts General Hospital, Charlestown, MA, United States,* [2]*Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Saxony, Germany*





A,B,C: Example SMS RF Pulses with resulting slice profiles; energy reductions that resulted from pulse settings used in this work. **D**: Slice profiles of pulses 1) and 3) at different off resonances. MultiPINS 3) shifts less and therefore achieves higher signal at offset. **F,G:** Coronal and axial views of color coded FA diffusion data acquired using MultiPINS pulse 3).

Target Audience: MR Scientists with an interest in RF Pulse design at Ultra High Fields and Simultaneous Multi Slice acquisitions

Purpose: Simultaneous Multi-Slice (SMS) acquisition [1] is a promising technique, which has gained much attention during the last years. It basic principle is to concurrently excite and encode multiple slices and use parallel imaging to unfold them. SMS significantly increases temporal efficiency of structural and EPI based acquisitions [2,3,4,5], particularly when controlled aliasing is employed to mitigate parallel imaging noise amplification [4,5]. At ultra high field strengths, Multiband (MB) RF pulses (Fig A), commonly used for SMS acquisition, can cause large energy deposition - limiting acquisition speed due to SAR constraints. The architecture of recently introduced of Power Independent of Number of Slices (PINS) pulses (Fig B) [6] allows for reduced RF power deposition to enable efficient spin echo and diffusion SMS acquisitions at 7T [7,8]. PINS excitation however comes at cost of increased off resonance dependency and lower RF pulse bandwidths (BW). Here we beneficially combine PINS and MB pulses to form a new *MultiPINS* RF pulse type with even better energy efficiency. This reduced energy can be traded off for shortened RF pulse; to decrease off resonance dependency and/or increase BW. To create a MultiPINS pulse, first a MB RF pulse is reshaped to follow k-space traversal of the blipped gradient waveform of PINS pulse (with the same slice thickness *d*, inter slice distance *D* and *BWTP*). The *reshaped* MB pulse can then be mixed directly with the PINS pulse to create a MultiPINS pulse with suitable excitation characteristic for SMS imaging (Fig C). To minimize SAR, optimal mixing ratio in the MultiPINS pulse (0% being pure PINS and 100% being pure MB pulse along PINS gradient trajectory) can be easily determined empirically prior to acquisition. With decreased SAR, the PINS sub pulse duration (*SPD*) in the MultiPINS excitation can be reduced to shorten the overall pulse duration at an acceptable cost of increased RF voltage and energy.

Methods: RF-energy was calculated for three different PINS/MultiPINS pulse cases (all with 61 sub pulses, *d*=1.4mm, *D*=35mm, Multiband factor *MB*=3, *BWTP*=2.5): type 1) *SPD*=70µs, Mix=0% (pure PINS); type 2) *SPD*=70µs, Mix=30% (low energy MultiPINS); type 3) *SPD*=40µs, Mix=40% (shortened MultiPINS) and compared to a pure conventional MB pulse with identical *BWTP* and duration. Slice profiles and off-resonance behaviors for these RF types were evaluated using Bloch Simulations. A diffusion-weighted dataset with 1.4mm isotropic resolution was acquired on a whole body 7T MR system (MAGNETOM, Siemens Healthcare, Erlangen, Germany) with a custom-built 32-channel head coil. In this sequence, MultiPINS (type 3) was employed for refocusing. We used: *TR*=3000ms, *TE*=69ms, 2xInPlane Acceleration, 75 slices, 3xMB slice-acceleration with Blipped-CAIPI shift of 3, 60 diffusion directions with b=1000s/mm^2, 7 interspersed *b0* images. One average was acquired, resulting in a total acquisition time of ~3.5 minutes. Data were corrected for motion and eddy currents (FSL), registered to a structural scan using Freesurfer. A color-coded FA map was calculated using DTK (http://www.trackvis.org/).

Results: Bloch Simulations (Fig. D) show similar on resonant excitation patterns for the three desired SMS slices in all the PINS/MultiPINS configurations. Additional excited side slices, typically located outside the FOV, are fully excited in the PINS case and partially excited in the MultiPINS case (this excitation is coming for the PINS component of the MultiPINS pulse). PINS pulse type1 has a duration of 11.4ms and an 18% SAR reduction compared to an *MB*=3 pulse of the same duration and *BWTP*. The MultiPINS Pulse type 2) has a matched duration to type 1) but a 51% reduced energy compared to the MB pulse. MultiPINS pulse (type 3) has an identical energy transmission as PINS pulse (type 1) but a shorter duration of 9.4ms. This shortened duration reduces slice shifting at off-resonant frequencies (Fig D) and therefore results in higher off resonant signal (Fig E), if a different off resonance behavior for excitation and refocusing pulse are used for low SAR fat suppression [10]. The acquired diffusion weighted data can be seen in a coronal and axial view in Fig. F ,G.

Discussion and Conclusion: This paper proposes a novel MultiPINS RF pulse design which combines MB and PINS pulses in order to reduce energy transmission and/or off resonance effects. In our example, we achieved an energy reduction of 40% for MultiPINS compared to PINS and 51% compared to MB. The MultiPINS pulse was used to acquire high-resolution in vivo SMS diffusion acquisition at 7T. Additionally, it can also be applied to other sequences, with more RF shots per time unit, such as spin echo fMRI [7] or turbo spin echo [8].

References: [1] Larkman DJ. JMRI(2001) [2]Moeller S. MRM(2009) [3]Feinberg D. PLOS ONE(2010) [4]Setsompop K. MRM(2012) [5]Breuer FA. MRM(2005) [6]Norris D. MRM(2011) [7]Koopmans PJ. NeuroImage(2012) [8]Eichner C. MRM(2013) [9]Norris D. MRM(2013) [10]Ivanov D. MRM(2010)