

# SAR Efficient Simultaneous Multislice Diffusion Weighted Imaging at 7T using PINS RF pulses

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**Target audience:** MR physicists

**Purpose:** Simultaneous multislice (SMS) imaging is an efficient way to speed up multislice 2D acquisitions by exciting several slices simultaneously and reconstructing them via parallel imaging algorithms [1]. Specifically, diffusion weighted imaging (DWI) profits largely when this technique is used [2,3]. However, at high field strengths SMS using conventional multiband pulses faces the challenge that SAR is a limiting factor regarding acquisition time and that, furthermore, in the standard implementation the summation of standard pulses to obtain a multiband pulse cannot meet the amplitude constraints of the RF amplifier. Specifically when using a twice-refocused DWI sequence, known for its advantageous eddy-current behaviour [4], these limits become prohibitive for fast DWI at 7T. Recently, Norris et al. [5] demonstrated a SAR efficient SMS approach by using RF pulses where RF power is independent of the number of slices (PINS) by multiplying a single slice pulse with a comb function. Here we demonstrate that the implementation of PINS pulses enables twice-refocused DWI at 7 Tesla without significant limitations due to RF power and amplitude constraints.

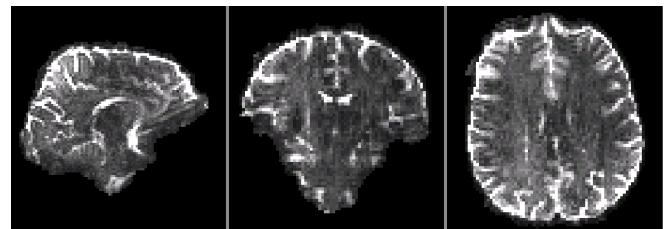
**Methods:** Experiments were performed on a 7T whole-body MR scanner (Siemens Healthcare, Erlangen, Germany) equipped with a gradient system achieving a maximum gradient amplitude of 70 mT/m and a slew-rate of 200T/m/s. In-vivo diffusion-weighted images were acquired on a healthy volunteer using a 32-element head coil (Nova Medical, USA) and the vendor-specific implementation of a twice-refocused spin-echo diffusion weighted EPI sequence [4] which was modified to enable to replace the standard sinc excitation and refocusing pulses with their matched PINS counterparts. The following parameters were used: TR/TE = 2400/81 ms, isotropic resolution of 2 mm (MA = 112 x 112, FOV = 224 mm, 84 slices interleaved including a SMS acceleration factor (AF) of 4, i.e. 21 slice packs, no slice gap), inplane AF = 3 (GRAPPA with 36 reference lines), readout BW = 1488 Hz/px (corresponding echo spacing = 0.78 ms), 60 diffusion directions with a b-value of 1000 s/mm<sup>2</sup>, and 6 b<sub>0</sub> images. Total acquisition time for the SMS scan was 2:50 minutes. The standard (single slice, i.e. non-SMS), non-diffusion weighted prescan using standard RF pulses matched to the PINS pulses regarding duration and BW had a TR of 9600 ms and was used as reference data for the SMS reconstruction. The RF pulse durations were 7.7 ms with a BWTP of 1.67 for both PINS and standard pulses. As the number of slices generated by the PINS pulse is limited only by the object dimensions and the coil sensitivity we employed a sagittal slice orientation to avoid exciting more than 4 slices simultaneously. The reconstruction was performed offline using an implementation of the SENSE-GRAPPA algorithm [6] implemented in Matlab. The FMRIB Diffusion Toolbox 2.0 as implemented in FSL was used to perform eddy current correction and diffusion tensor fitting (dfit).

**Results and Discussion:** SAR levels were 100% for the standard DWI sequence using the same duration and BWTP RF pulses and a TR of 9.6 s compared to a SAR level of 52% for the SMS scan. While we show that a factor 4 acceleration can achieve reasonable results, it is probably more feasible to use a factor of 3 slice acceleration. This would reduce the SAR benefit (in PINS the SAR level is independent of the number of slices), however, the acquisition would still not be SAR limited. A potential issue is the relatively long pulses needed for PINS pulses which may affect the slice profile, and could be mitigated by using higher slew rate gradients to increase the time spent on RF pulses in PINS.

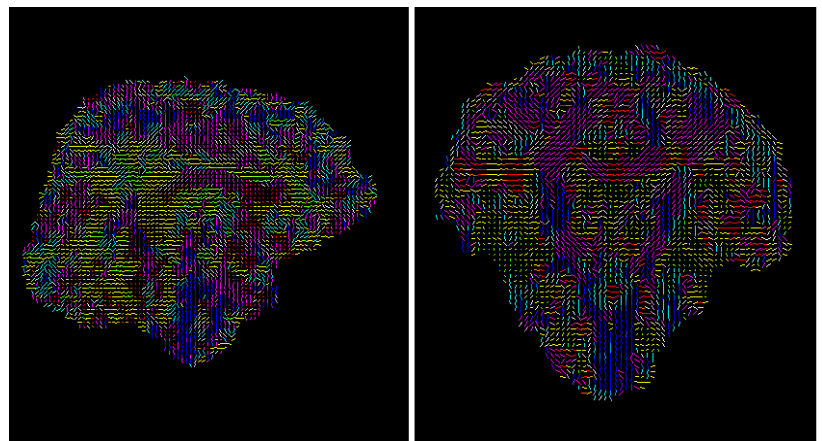
**Conclusion:** We have shown that it is possible to acquire a diffusion dataset with 2 mm isotropic resolution and 60 diffusion directions in less than 3 minutes using SMS imaging and PINS RF pulses at 7T without being limited by RF power.

**References:** [1] Larkman et al., JMR 2001 [2] Feinberg et al., PlosOne 2011 [3] Setsompop et al., NI 2012 [4] Reese et al., MRM 2003 [5] Norris et al., MRM 2011 [6] Blaimer et al. JMRI 2006

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**Figure 1:** Three orthogonal slices with no diffusion weighting (b=0 image) after processing and model estimation using FDT



**Figure 2:** Direction of the principal diffusion direction, 2 mm isotropic resolution, AF 3 (inplane) x 4 (slice), 60 diffusion directions, b = 1000 s/mm<sup>2</sup>, TA=2:50 minutes