Consistent Signal for non-CPMG echo trains

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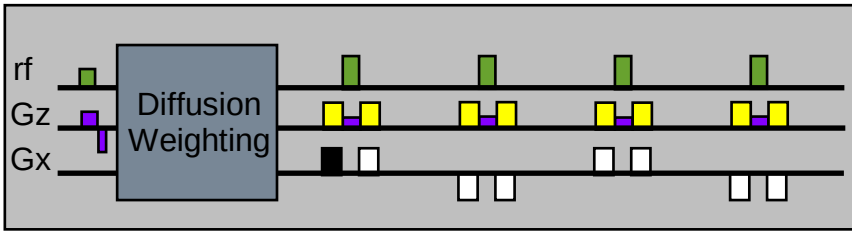

Fig. 1. Example of proposed mixing scheme. Normal crushers (yellow) are on Gz. The first mixing crusher (black) on Gx after diffusion weighting creates a uniform distribution of starting phase θ in each pixel. The remaining crushers (white) are played in pairs which unwind this phase for readout, and then rewind it back before the next pulse, with zero net area in each echo.

Introduction Non-CPMG FSE echo trains are inherently unstable, but are a necessary consequence of DW FSE methods. Methods to address this problem include rf phase cycling to stabilize the echo train and mitigate signal loss, including MLEV(1) and the quadratic phase method of LeRoux(2). For both of these methods, the signal amplitude of the echo train is more stable, but still varies for some echoes with the pixel's starting phase θ after diffusion weighting. This can lead to variation in signal magnitude across individual images and between differently diffusion-weighted data sets, compromising the quantitative information in combined diffusion-weighted images (each with a different, spatially-varying starting phase θ and corresponding slight difference in signal).

Method: For all FSE methods, a crusher gradient (yellow crusher, Fig. 1) is used to uniformly distribute inter-echo spin precession in each pixel. This work adds an additional crusher, illustrated and explained in Fig. 1, which removes the variability in a non-CPMG echo train due to the starting phase induced by motion during diffusion weighting. Data were collected with and without the proposed mixing crushers, using a 32-echo FSE sequence on a GE 3T scanner to scan a small vial of water, with prescribed refocusing flip angles of 150˚ and 120˚. The phase of the 90˚ excitation pulse was varied from 0 to 180˚ to vary the spin phase across the same range. Results are shown in Fig. 2.

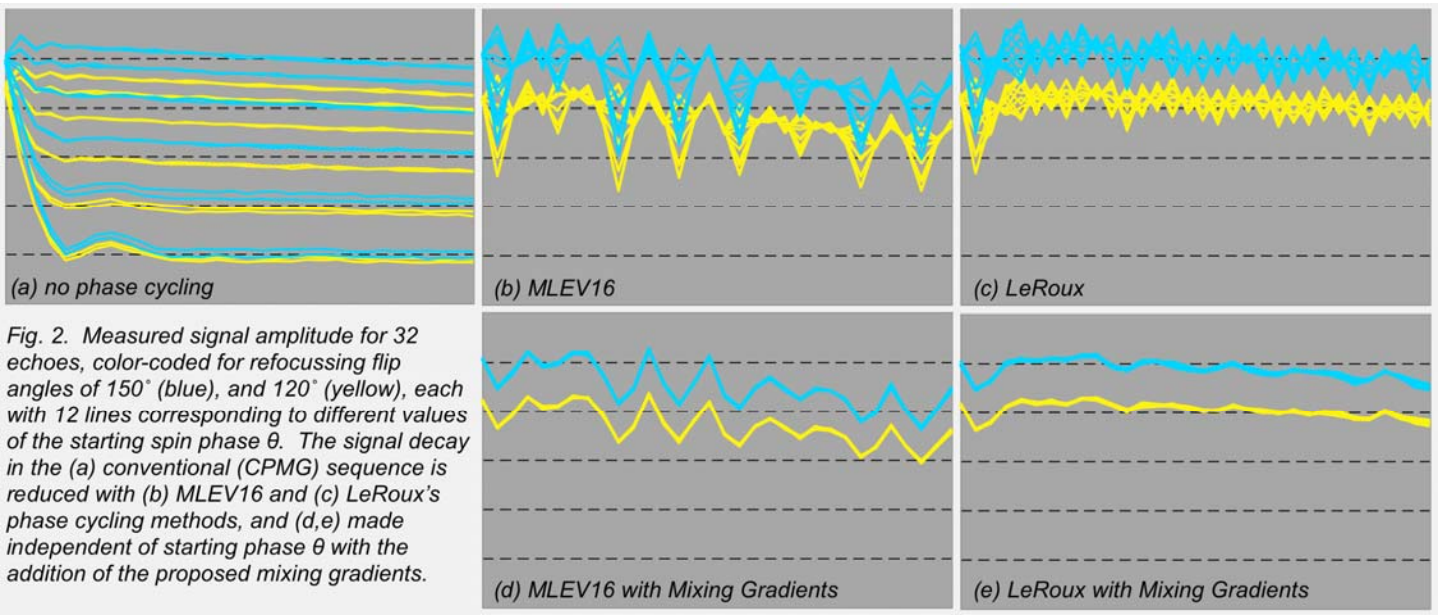

Fig. 2. Measured signal amplitude for 32 echoes, color-coded for refocussing flip angles of 150˚ (blue), and 120˚ (yellow), each with 12 lines corresponding to different values of the starting spin phase θ. The signal decay in the (a) conventional (CPMG) sequence is reduced with (b) MLEV16 and (c) LeRoux's phase cycling methods, and (d,e) made independent of starting phase θ with the addition of the proposed mixing gradients.

Results and Conclusions: As shown in Fig. 2, echo trains are stabilized using the proposed mixing gradients due to an averaging of all θ pathways. It is striking that LeRoux's method produces a very uniform magnitude across both even and odd echoes, even for small refocusing flip angles. This work illustrates a simple method to ensure signal consistency in phase-cycling methods for non-CPMG experiments, which reduces artifact and increases accuracy for diffusion weighted FSE MRI.

References: 1. Levitt, Freeman, J Magn Reson 43, p65. 2. LeRoux, J Magn Reson 155, p278.

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