Suppression of banding and transient signal oscillations in balanced SSFP using a spoiled RF pre-phasing approach

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Introduction: Balanced steady state free precession (bSSFP) offers high SNR efficiency and unique contrast mechanisms, but is prone to banding artifacts and transient signal oscillations. We present an RF "pre-phasing" approach for suppression of banding and transient oscillations in bSSFP.

Methods: The proposed pulse sequence is a modification of the RF pre-phasing method in [1], and is illustrated in Fig. 1(b). Pulse $B1_a$ tips the spins toward the transverse plane with an in-plane phase corresponding to the local off-resonance $\Delta f(x,y)$, while $B1_b$ tips the spins back toward the z-axis at the end of TR. A gradient spoiler is played out after each tip-up pulse [2].

The ideal excitation pattern produced by the $B1_a$ sub-pulse has uniform intensity and an in-plane phase variation $\theta(x,y) = -\pi\Delta f(x,y)\,TR$. To produce such a pattern it is necessary to use either multiple transmit coils as proposed in [1], a 3D RF pulse as done here, or a combination of the two. In this work a slice-selective tip-down pulse ($B1_a$) with 2D in-plane phase variation was designed using a small-tip method with an echo-volumar excitation k-space trajectory and a measured B0 map, with (k_x,k_y) phase-encoding locations selected using a sparse approximation approach [3]. The tip-up pulse ($B1_b$) was created by first designing an intermediate tip-down pulse $B1_{b,int}$ using the *negative* of the measured B0 map. The tip-up pulse was then obtained as the negative, time-reverse of $B1_{b,int}$ (with the x and y gradients also negated). The proposed 3D RF pulse design approach is fully compatible with parallel excitation, and as such offers a general approach for creating the desired sub-pulses given the available RF transmission hardware.

Transient signals were observed in a ball phantom (measured T1/T2=996/411 ms) with a birdcage head coil on a GE 3T scanner. The B0 shim was set using the scanner's auto pre-scan function. Two different sequences were compared: (1) Balanced SSFP with two back-to-back RF pulses of equal phase, and (2) the proposed method using echo-volumar 3D RF pulses with 13 phase-encoding locations. No special spin preparation (e.g. catalyzation) was used for either method. The free precession time (Tfree), i.e. the time from the end of one RF excitation to the beginning of the next, was 10 ms. Acquisition parameters: 2DFT CINE; 50 temporal frames; temporal resolution one TR; 5 second pause after each sequence of 50 RF excitations.

Steady-state signals were observed with a similar setup. A short (~2 mm) segment of ferrous wire was placed in the vicinity of the phantom to induce non-linear B0 inhomogeneity, and the B0 shim was set using the scanner's auto pre-scan function.

Results: Figure 2 shows that the proposed method is expected to remove the bands, at the cost of reduced signal compared to an on-resonance conventional bSSFP acquisition. The relative signal loss increases with increasing pre-phasing error $\Delta\theta$. Figure 3 shows 5 snap-shots of the transient acquisition, and demonstrates excellent suppression of transient signal oscillations with the proposed method. Figure 4 shows steady-state images for the two methods used in the transient experiment and for the proposed method with the spoiler turned off.

Discussion and Conclusions: Spoiled RF pre-phasing suppresses both banding and transient signal oscillations in bSSFP imaging, at the cost of reduced signal relative to an on-resonance conventional bSSFP acquisition. The proposed approach is fully compatible with parallel excitation, which will dramatically reduce the total RF pulse duration. We anticipate that the proposed method will allow artifact-free bSSFP imaging in regions with predominantly smooth B0 variation such as the brain, and for applications with relatively long TR such as passband bSSFP functional MRI [4-5].

References: [1] Heilman et al, ISMRM 2009, p251; [2] Nielsen et al, ISMRM Parallel MRI Workshop, Santa Cruz, 2009; [3] Yoon et al, ISMRM 2009, p2595; [4] Bowen et al, ISMRM 2005, p119; [5] Lee et al, MRM 59:1099-1110 (2008).

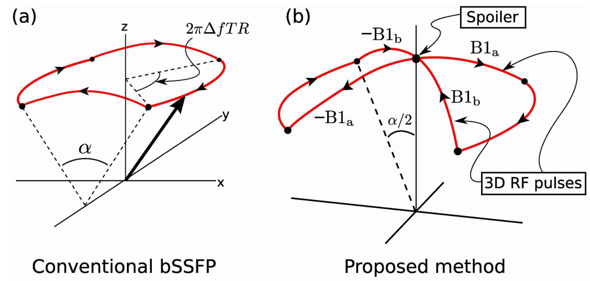

Figure 1: (a) Conventional bSSFP and (b) the proposed spoiled pre-phasing scheme.

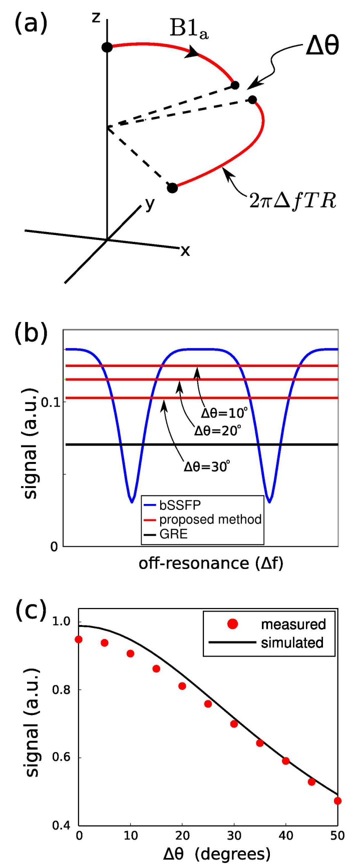

Figure 2: Effect of pre-phasing error Δθ on steady-state signal. (b) Simulated signal profiles. (c) Signal vs. Δθ, normalized to the conventional bSSFP on-resonance signal.

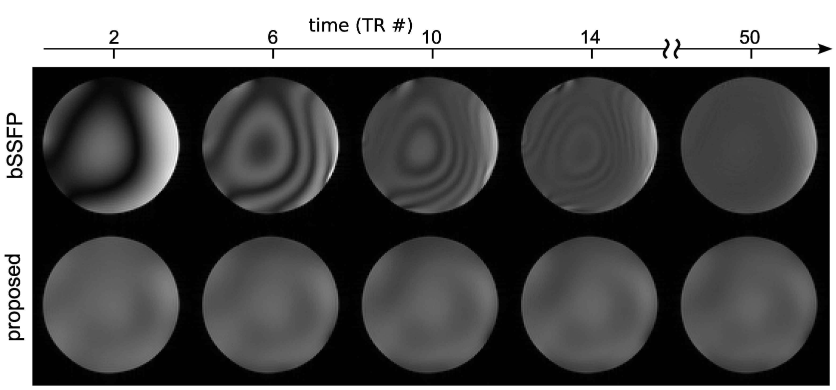

Figure 3: Observed transient signal in a ball phantom for conventional bSSFP (top row) and the proposed method (bottom row). (T1/T2/Tfree = 996/411/10 ms; alpha = 20º)

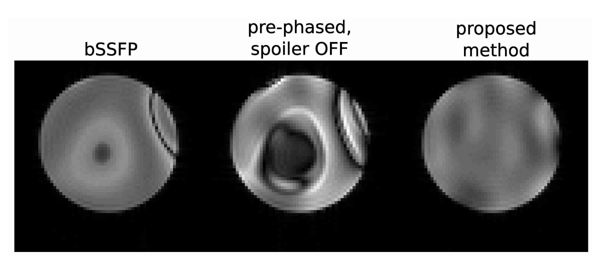

Figure 4: Observed steady-state signal in a ball phantom. (T1/T2/Tfree = 996/411/20 ms; alpha = 20º)