Wideband SSFP: SSFP with imaging bandwidth greater than 1/TR

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Introduction: The SSFP signal provides superior SNR and image quality compared to gradient echo techniques, but is highly sensitive to resonance frequency [1]. The "bandwidth" of conventional SSFP is less than 1/TR (with signal nulls occurring every 1/TR in resonance frequency). We introduce a new technique, which we call Wideband SSFP (wbSSFP). Two alternating TRs are used with excitations that alternate in sign to establish a steady state with a pass band up to two times wider than conventional SSFP. For a given bandwidth requirement, this permits the use of a longer readout duration allowing high-resolution imaging (requiring large readout gradient areas) and time-efficient imaging (with EPI or spiral readouts with oscillating gradients). At 3T this is enabling for many applications.

Methods and Results: Simulations characterizing steady state magnetization and profiles were performed in MATLAB. The wbSSFP pulse sequence and signal profiles are shown in Figure 1. Conventional SSFP is the case where TR_s = TR. As TR_s is reduced, the central pass-band widens, accompanied by a decrease in signal amplitude. Using two repetition times, the bandwidth improvement is limited to 2x. As shown in Figure 2, in steady state, the magnetization path is effectively rotated about the y axis, creating two echoes: a strong one during the short TR and a weaker one during the long TR. Both echoes have a wider imaging bandwidth than conventional SSFP (TR_s = TR).

Experimental validation was performed on a GE Signa 1.5T scanner using a slab phantom (containing doped water T1,T2 ≈ 100 ms) and a 2D wbSSFP sequence. A linear shim was applied along one in-plane direction to observe the spectral response. Figure 3 contains measured signal profiles when TR_s = TR and TR_s = TR/2.

Discussion: Shortening TR_s results in a trade-off between widening the pass-band and lowering signal during the long TR echo (see Fig. 1) while boosting signal during the short TR. While TR_s may be unusable for imaging (too short to contain a readout), it may be possible to acquire a navigator echo during this time. If there is no acquisition during TR_s, it would be possible to use a composite RF pulse that combines the $-\alpha$ and $+\alpha$. Interestingly, this is comparable to doing conventional SSFP with a (-1,1) spectral-spatial pulse for fat-suppression [2,3], or missing-pulse SSFP without gradients [4].

There is a small dip in the profile exactly on-resonance, because relaxation has a bigger effect than precession for those spins. This dip becomes wide and potentially problematic when T2 ≠ T1 and both are ≈ TR (which is rare, but may occur in contrast enhanced imaging).

|M| the magnetization vector amplitude is closer to Mo in wbSSFP than in conventional SSFP, for all spins in the pass-band. Therefore the approach to steady state is expected to be more rapid, and catalyzation easier (i.e. would not require magnitude scaling).

Conclusion: Wideband SSFP provides the SNR and contrast benefits of SSFP, while improving the spectral bandwidth by up to a factor of 2. Controlled phantom studies confirm the expected bandwidth improvement. We are currently performing more rigorous phantom experiments, and plan to apply this technique to 3 Tesla cardiac SSFP imaging (which is significantly limited by off-resonance).

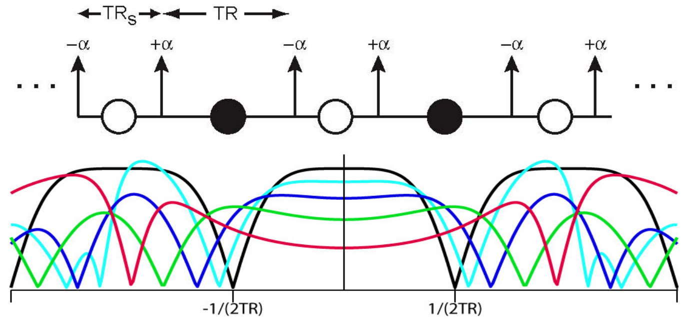

Figure 1: *(top) wbSSFP pulse sequence and (bottom) signal profiles during TR for TR_s = {TR, 0.8TR, 0.6TR, 0.4TR, and 0.2TR} in {black, cyan, blue, green, and red}. Profiles assume T1 = T2 >> TR and α = 90º.*

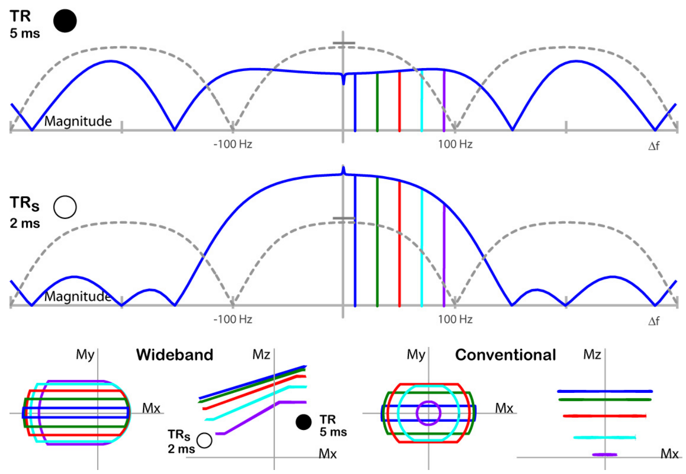

Figure 2: *Illustration of steady-state for TR_s = 2 ms and TR = 5 ms. (top) signal profiles during TR and TR_s and (bottom) magnetization path compared with conventional SSFP where TR_s = 5 ms. Simulations assume T1/T2 = 1000/300 ms and α = 70º.*

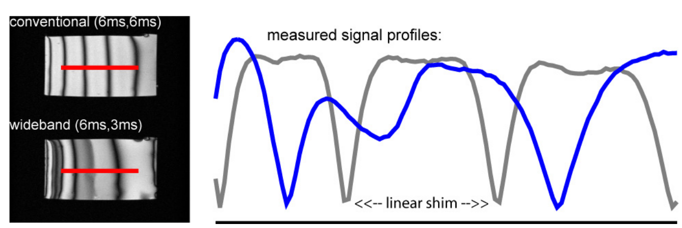

Figure 3: *Measured signal profiles from a uniform block phantom with a linear x-shim at 1.5T, with TR = 6 ms: (gray) conventional SSFP with TR_s = TR, and (blue) wbSSFP with TR_s = TR/2. 60% bandwidth improvement is observed. The signal dip in the wbSSFP profile is presumably due to the short T1 and T2 of the test object.*

References:

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