A Low-Power Asymmetrically-Selective Adiabatic Pulse

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Introduction: Adiabatic spectral-spatial pulses [1-3] using a hyperbolic-secant [4] temporal modulation have been shown to provide robust refocusing performance in the presence of B_1 inhomogeneity for PRESS-localized spectroscopic imaging sequences. However, the available peak B_1 field typically limits spectral bandwidth. Reduced peak-power adiabatic full-passage (AFP) pulses such as the HSn [5-6] family of pulses can reduce peak-power requirements and increase spectral bandwidth but at a cost of reducing spectral selectivity. We present a novel AFP design that provides peak power reduction without losing selectivity on one side of the pulse, and demonstrate it's application in designing a spectral-spatial refocusing pulse.

Methods: A single-sided HSn pulse (SSHSn) was designed to provide offset-independent adiabaticity using the methods of [5]. In order to maintain single-sided selectivity an HS1 envelope sweep is used for one half of the pulse and an HSn (n>1) for the other. Figure 1a shows $d/dt\,\tau(t)$, where $\tau(t)$ is desired to be mostly linear for $t < 0$, and t^n for $t > 0$. A smooth function that achieves this over normalized time $-1 < t < 1$, with transition beginning at T_c (normally -0.2) is:

$$\frac{d}{dt}\tau(t) = \begin{cases} -1+\dfrac{T_c}{2} & -1 \le t \le T_c \\ \left[1-\dfrac{T_c}{2}\right]\left[\frac{1}{2}\tanh\left(4(T_c-2t)/T_c\right)-\frac{1}{2}\right] & T_c < t < 0 \\ nt^{n-1} & 0 \le t \le 1 \end{cases}$$

The time warping $\tau(t)$ is obtained by numerical integration. The normalized envelopes and frequency sweeps are then derived as shown in Fig. 1c-d [5].

A spectral-spatial refocusing pulse was designed as in [3] using our novel SSHSn temporal modulation, but with a spectral bandwidth ΔBW higher than the desired final BW. The refocusing pulse is then modulated by $\exp(i2\pi t\cdot\Delta BW/2)$ to relocate the sharp spectral band edge. The second refocusing pulse is given by time-reversing the first pulse.

Results: HS1, SSHS4 and HS2.3 pulses were designed to provide a normalized BW of 0.2. Figure 2a shows the pulse envelopes when scaled to provide comparable adiabatic behavior. The SSHS4 and HS2.3 pulses both provide a 33% reduction in peak power requirements. As shown in Fig. 2b, the SSHS4 pulse maintains spectral selectivity for the negative frequency edge while the HS2.3 transition is approximately 20% larger.

Figure 3a illustrated the overlapping spectral profiles of the two 26-ms SSHS4 spectral-spatial refocusing pulses designed to excite a 850-Hz BW and a 4-cm thick slab. The nominal bandwidth of each individual pulse was 925 Hz. The 25% overdriven SSHS4 pulses had a peak RF amplitude of 0.133G, 28% less than a 25% overdriven HS1 pulse that had a peak amplitude of 0.185G. The M_{xy} spectral-spatial profiles following the pair of refocusing pulses were acquired on a GE Signa 1.5-T scanner, with a gradient shim simulating the spectral dimension. Figure 3b-d shows the excellent agreement between the SSHS4 and HS1 magnitude profiles. The SSHS4 phase variation in the spectral dimension is nearly perfectly linear and is easily compensated by adjusting the echo time.

Discussion: A novel AFP SSHSn pulse has been developed that provides 33% peak power reduction compared to an HS1 pulse, but maintains a single-sided selectivity. When used as a pair of refocusing pulses, the full HS1 selectivity can be maintained. This will enable much larger spectral bandwidths to be resolved in PRESS-localized sequences without giving up spectral selectivity.

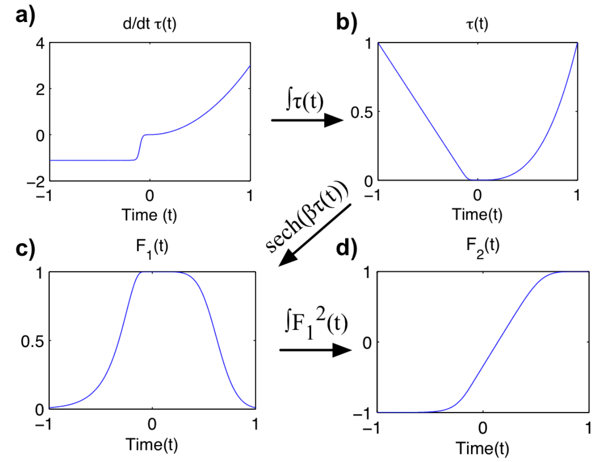

Figure 1: Derivation of single-sided HSn (SSHSn) normalized magnitude $F_1(t)$ and frequency sweeps $F_2(t)$.

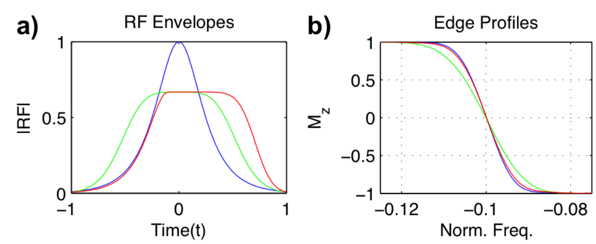

Figure 2: a) HS1 (blue), HS2.3 (green) and SSHS4 (red) envelopes. b) Negative-edge inversion profiles.

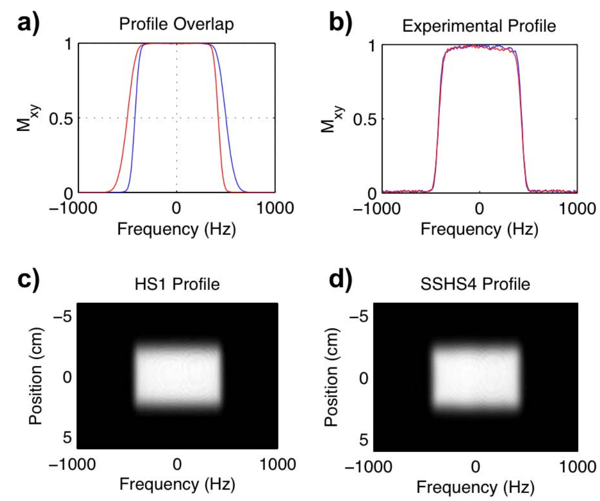

Figure 3: a) Illustration of overlapping spectral profiles from pair of spectral-spatial SSHS4 refocusing pulses. Experimentally acquired spin-echo Mxy after pair of refocusing pulses b) HS1 and SSHS4 spectral profiles c-d) spectral-spatial profiles.

References: [1] Cunningham *et al.*, Proc. ISMRM, p72, 2007. [2] Balchandani *et al.*, MRM, 59(5):973–979, 2008. [3] Xu *et al.*, MRI, 26(9):1201–6, 2008. [4] Silver *et al.*, Phys. Rev. A, 31:2753–55, 1985. [5] Tannu's *et al.*, J Mag Res. Series A, 120:133–7, 1996. [6] Garwood *et al.*, J Mag Res, 153(2):155–77, 2001.

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