Robust Long-T_2 Suppression Pulses

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Introduction:

Ultra-short echo time (UTE) imaging has recently become of interest for its possible clinical applications [1,2]. Without long T_2 suppression, UTE images will be dominated by the long T_2 components. This abstract compares various approaches to long T_2 suppression based on low-amplitude composite RF pulses. This was originally approached by applying a low amplitude 90° RF pulse that allows short T_2 species to recover over its duration [3]. The low amplitude of this pulse makes it very volatile to B_1 inhomogeneities. Image subtraction using multiple echo times has also been used to remove long T2 species [4], although an RF suppression technique is desirable to reduce scan times and motion artifacts.

Theory/Methods:

The pulses compared here are based primarily on composite pulses used originally in NMR [5]. The desired end result is a 90° tip angle for only long T_2 species that will be followed by a dephaser. These pulses must have very low amplitude so that short T_2 species will not be affected by the pulse.

The first pulse is a variation of a 90_{0°-90_{90°[6] where a z-gradient crusher is applied between the two pulses to improve the off-resonance performance. pulse uses the crusher to return all spins to the M_Z axis before applying the second pulse The second composite pulse is a 90_{0°-180_{225°-90_{0°, a symmetrized version of the 90_{0°-90_{90° that provides a larger B_0 bandwidth [7]. A $180_{97.2^\circ}$-$360_{291.5^\circ}$-$180_{97.2^\circ}$-90_{0° composite pulse is also included in this comparison because it is even more resistant to B_1 variations [5,8]. Composite pulses with more pulse elements will require significantly longer pulse times to achieve reasonable T_2 profiles.

Results:

Each of the RF pulses was simulated using the Runge-Katta algorithm to solve the Bloch equation, neglecting T_1 decay. The pulses are compared based on pulse length, long T_2 suppression, B_0 bandwidth, and robustness to B_1 variation. The long 90_{0° RF pulse is included for comparison. Table 1 shows a summary of these properties for each of the different pulses, where the pulse lengths are such that the RF amplitude is constant over the duration. Figure 1 shows how much longitudinal magnetization (M_Z) remains for various T_2. The mesh plots in figure 2 show the remaining longitudinal magnetization for T_2 = 100 ms, plotted vs. B_0 and B_1 variations.

For all of these pulses, shortening the pulse length will reduce the T_2 cutoff but enhance the B_0 bandwidth. Depending on the desired T_2 species to be imaged, a tradeoff can be made here.

The90_{0°-90_{90° is presented in Table 1 for comparison, but for most applications its B_0 bandwidth is much too small. It obtains a factor of 3 improvement in B_1 robustness at the expense of a factor of 4 in pulse length.

The 90_{0°-crusher-90_{90° also requires approximately 4 times the pulse length of the 90_{0° to obtain a similar T_2 profile, and is 3 times more robust to B_1 variations. It has a similar B_0 bandwidth to the 90_{0° pulse, which is a significant improvement over the 90_{0°-90_{90}. The crusher was assumed to be ideal in the simulation, but this should not change the performance significantly. A pattern of 90-crusher's could also be repeated multiple times for increased B_1 robustness as long as the dephasers do not introduce any coherent echoes.

The 90_{0°-180_{225°-90_{0° pulse requires 16 times the pulse length to achieve a similar T_2 profile to the 90_{0°. The significant pulse length leads to a small B_0 bandwidth, but this pulse offers an alternative to using a crusher.

The $180_{97.2^\circ}$-$360_{291.5^\circ}$-$180_{97.2^\circ}$-90_{0° pulse is especially robust to B_1 variations, but it is only able to achieve the same T_2 profile as the other pulses with a length of nearly 400 ms. The pulse length of 90 ms presented is a compromise that achieves a reasonable T_2 cutoff for UTE imaging, has a moderate B_0 bandwidth, and is the most robust of the pulses to B_1 variations.

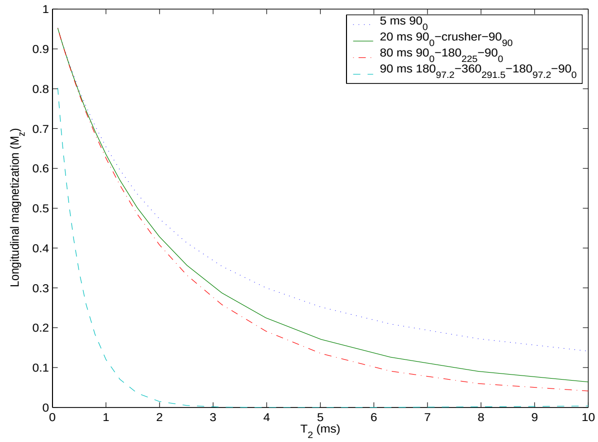

Figure 1: T_2 profile for various pulses from numerical simulations

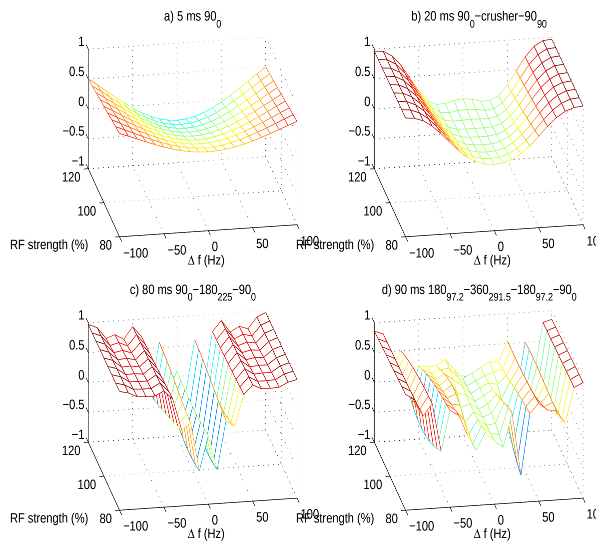

Figure 2: B_1-B_0 profiles of resulting longitudinal magnetization for T_2 = 100 ms, where the Δf values are given for 1.5T.

Discussion:

Each one of the RF pulses presented is a significant improvement in B_1 robustness over the long 90_{0°. Of these pulses, the 90_{0°-crusher-90_{90° has the best bandwidth and shortest pulse time, while the 90_{0°-180_{225°-90_{0° and the $180_{97.2^\circ}$-$360_{291.5^\circ}$-$180_{97.2^\circ}$-90_{0° perform better with B_1 variations. In terms of T_2 cutoff and B_0 bandwidth, these two pulses are comparable except that the $180_{97.2^\circ}$-$360_{291.5^\circ}$-$180_{97.2^\circ}$-90_{0° require a significantly longer pulse length. Investigation will continue into other pulses, including frequency modulated pulses, while beginning phantom and in-vivo testing.

Pulse	*Length (ms)*	*T_2 cutoff (ms)**	*B_0 bandwidth (Hz) ***	*B_1 robustness****
90_{0°	5	6.7	[-50.4, 50.4]	[-.309, .309]
90_{0°-90_{90°	20	4.5	[-2.8, 2.8]	[.0955, .0995]
90_{0°-crusher-90_{90°	21	4.5	[-40.5, 40.5]	[.0955, .0995]
90_{0°-180_{225°-90_{0°	80	3.9	[-3.1, 3.1]	[.0807, .0807]
$180_{97.2^\circ}$-$360_{291.5^\circ}$-$180_{97.2^\circ}$-90_{0°	90	1.07	[-27.5, 14.3]	[.0213, .0213]

Table 1 - Summary of various long T_2 suppression pulse parameters
* T_2 at which 20% of initial M_Z remains. ** Frequencies at 1.5T between which less than 20% of initial M_Z remains. *** M_Z values for RF powers of [120%, 80%], neglecting T_2 decay.

References:

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