Robust Long-$T_2$ Suppression Pulses

P. E. Larson1, D. G. Nishimura1
1Electrical Engineering, Stanford University, Stanford, CA, United States

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 $T_2$ 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 $90°-90°$ pulse where a z-gradients 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 $90°-180°-90°$, a symmetrized version of the $90°-90°$ that provides a larger $B_0$ bandwidth [7]. A $180°-360°-180°-90°$ 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-Kutta 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 $90°$ 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.

The $90°-90°$ pulse is shown 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 $90°$-crusher-$90°$ also requires approximately 4 times the pulse length of the $90°$ 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 $90°$ pulse, which is a significant improvement over the $90°-90°$. The crusher was assumed to be ideal in the simulation, but this should not change the performance significantly. A pattern of 90-90-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 $90°-180°-90°$ pulse requires 16 times the pulse length to achieve a similar $T_2$ profile to the $90°$. The significant pulse length leads to a small $B_0$ bandwidth, but this pulse offers an alternative to using a crusher.

The $180°-360°-180°-90°$ 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.

Discussion:

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

<table>
<thead>
<tr>
<th>Pulse</th>
<th>$T_2$ cutoff (ms)</th>
<th>$B_0$ bandwidth (Hz)</th>
<th>$B_1$ robustness***</th>
</tr>
</thead>
<tbody>
<tr>
<td>$90°$</td>
<td>5</td>
<td>6.7</td>
<td>[-50.4, 50.4]</td>
</tr>
<tr>
<td>$90°-90°$</td>
<td>20</td>
<td>4.5</td>
<td>[-2.8, -2.8]</td>
</tr>
<tr>
<td>$90°$-crusher-$90°$</td>
<td>21</td>
<td>4.5</td>
<td>[-40.5, 40.5]</td>
</tr>
<tr>
<td>$90°-180°-90°$</td>
<td>80</td>
<td>3.9</td>
<td>[-3.1, 3.1]</td>
</tr>
<tr>
<td>$180°-360°-180°-90°$</td>
<td>90</td>
<td>1.07</td>
<td>[-27.5, 14.3]</td>
</tr>
</tbody>
</table>

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 $T_1$ decay.

References: