Inversion of a Non-CPMG Fast Spin Echo train.

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Introduction

The non-CPMG sequence (1) has been introduced to permit acquisition in the fast spin echo mode even when the CPMG (Carr-Purcell-Meiboom-Gill) condition cannot be fulfilled, as in diffusion imaging (2)(3)(4). It has recently been shown (5) that this sequence can be easily inverted, permitting an almost perfect return to equilibrium. The technique was aimed at maintaining the longitudinal magnetization in hyperpolarized ^{13}C imaging and was restricted to nutation angles above 160°. We explore here the possibility of using longer and more efficient stabilization scheme as the one given in (6), enabling the use of lower nutation angles.

Method

One can naively inverse a sequence by reversing the order of rotations and by changing the sign of each one of them. The problem of this approach is that, if nutations and controlled precessions (RF phase setting) are easily compensated, it is not the case of the free precession Ω. The solution may rely on the introduction

of perfect π nutation pulses, but again this should not be considered as a realizable solution. The nCPMG preparation period is special in the sense that it tends to create a rotation which is *symmetrical* around a frequency, and that frequency may always be set as zero. This is what is summarized in Figure 1 where the set of precession offset $\{\delta_i, i=1..P\}$ puts the original x magnetization along a distribution which is symmetrical around 0. Identically, it will put y and z along two symmetrical distributions. In consequence an hypothetical sequence where all free precession angles are reversed (middle row of figure 1) would give the same result. Then, (left of bottom row of figure 1) taking the naïve inverse of that second sequence, one obtains a realizable sequence where the precession and nutations angles are inversed, but where the free precession regains its natural sign. Finally, one may want to recover the original sign of nutations by inserting

π *precessions* (bottom row, right), but this is only for conceptual simplification. The remaining difficulty is that the center of symmetry at the end of the preparation sequence is not clearly defined, and generally not at frequency zero (apart in the case of recent designs (7)). This center translates by Δ between each echo along the Ω axis, and is at a position, at the echo P following the RF pulse P, equal to $\Omega_c=\delta(P)+\Delta/2-\pi/2$. It suffices to subtract this value from all controlled precessions $\{\delta_i, i=1..P\}$ to be in the condition of figure 1 and obtain directly the inverse of the preparation period. If L echoes are inserted after the preparation and before the inversion it suffices to add also $L\Delta$ to the precession angles of the inversion.

Figure 1: The stabilization of nCPMG creates a rotation which is symmetrical around zero frequency. This is what permits its inversion.
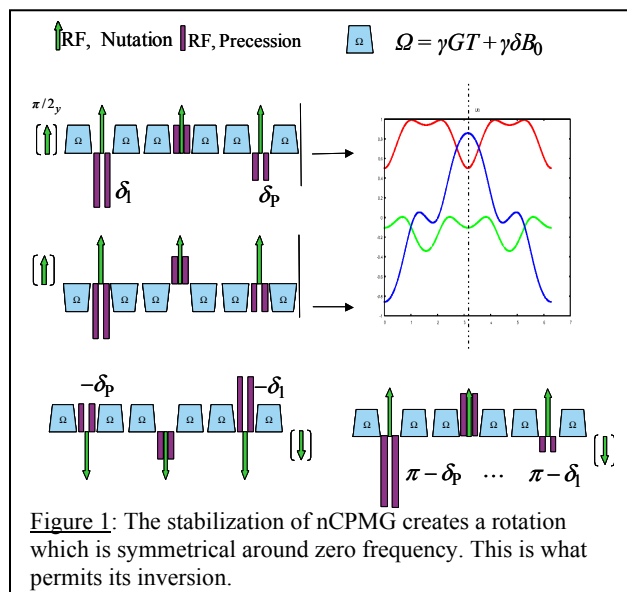
Simulation Results

The figure 2 shows the global voxel magnetization response when the original magnetization is along x, for the stabilization law given in (6). The nutation angle of refocusing pulses is 130°. The number of echoes is 64, and as the stabilization law in (6) extends up to 71 echoes, only the P=32 first values is used, and the inversion begins from echo 33. The left row depicts the global magnetization (signals) when the original magnetization is along X (top) or Y (bottom). The two other rows give the distribution of the corresponding magnetization at echo 32 and echo 64. This last row shows the quality of the return to the original position.
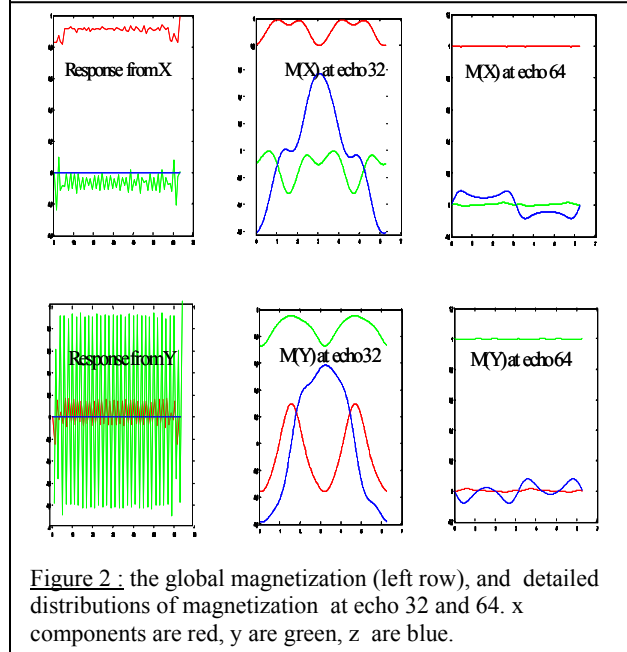
Discussion

The inversion of the non-CPMG sequence has been applied already to ^{13}C (8), but to be useful in classical imaging, lower nutation angles must be considered. The simulation shown here tends to prove that the theory is verified also at lower angle. Now, as pointed out in (6) the usefulness of such 'Driven Equilibrium' is restricted to echo train length short enough compare to transverse relaxation time T_2.

Figure 2 : the global magnetization (left row), and detailed distributions of magnetization at echo 32 and 64. x components are red, y are green, z are blue.

References

(1) P. Le Roux, JMRE 155 p 278-292, 2002. (2) Bastin, M.,*Magn. Reson. Med.* 48:6-14. (3) Oner A.Y. et al. *AJNR*, 28: 575-580, 2007. (4) Z. Li et al. ISMRM 2009 p.3515. (5) P. Le Roux et al. ESMRMB 2009 no 114. (6) P. Le Roux, ISMRM 2006, p.3368. (7) P. Le Roux, ISMRM 2009 p.2657. (8) Yi-Fen et al. ENC 2009, p.111