Analysis of TRASE Echo Train Pulse Sequences for RF Imaging

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Introduction: TRASE (Transmit Spatial Encoding) (1-6) is an RF-only k-space imaging method, which has the potential to significantly reduce MRI system costs in some applications by the elimination of the conventional gradient system. TRASE exploits gradients in RF phase rather than resonant frequency to achieve spatial encoding. For 3D imaging a minimum of 4 uniform B1 fields each with a unique linear B1 phase gradient is required. A +X phase gradient is given by: B1 = |B| exp(i x.G_1). The simplest 1D imaging experiment requires two equal and opposite B1 phase gradients ($G_{1B} = -G_{1A}$). A hard pulse echo train sequence with refocusing pulses transmitted alternately on the A and B fields: 90_A [180_A echo 180_B echo $]_{N/2}$ is used. This results in subsequent echoes being encoded progressively further out in k-space, since for any given point in the sample, each subsequent refocusing pulse imparts an additional, spatially-dependent constant phase increment. The size of the phase increment is proportional to the distance from the (effective) coil origin. **Aims:** The aim of this study is to design improved versions of the 1D TRASE imaging sequence. Since the k-space coordinate increases down the echo train, achieving high resolution imaging corresponds to maintaining echo amplitude and steady phase evolution behaviour for the later echoes. Sequence performance is studied with respect to off-resonance and B1 inhomogeneity performance, and elimination of artifacts.

Theory: TRASE requires only a single sequencer and transmit channel, however the sample sees a complete set of pulse sequences - because the use of more than one phase gradient means that relative pulse phase is a function of position within the sample. This is significant as pulse sequence behaviour can be highly dependent on relative pulse phases. For instance CPMG (90x-180y-180y-…) is very well compensated for pulse errors, whereas the sequence 90x-180x-180x-… is not. Optimization of even a single TRASE experiment therefore requires simultaneous consideration of a pulse sequence set. We will focus on the use of refocusing pulse phase to optimize sequence performance for immunity to B0 and B1 errors. The phase of each pulse is potentially a free parameter in sequence design. In overview the imaging and reconstruction procedure consists of 3 steps: **Step A)** Apply echo train pulse sequence with chosen refocusing pulse phases, collecting echo data (with a single k-space point / echo); **Step B)** Rephase echoes to account for the phases used in Step A so that for every sequence in the set (i.e. for every location in the sample) the phase progresses linearly with echo number; **Step C)** FFT to reconstruct 1D profile.

Simulation Methods: For 1D TRASE simulations echo train and sample parameters were selected to be non-ideal, but for conditions under which CPMG nevertheless works well: 64 echoes, refocusing pulses: 200us rectangular, 170^O flip angle, excitation pulse: 90^O, 200us length; sample: 400Hz bandwidth (flat frequency distribution), relaxation ignored. In all experiments refocusing pulses alternated between coil A and coil B as this is the requirement for spatial encoding with subsequent echoes sampling successive k-space locations. Sequence performance was evaluated by the amplitude envelope of the echo train (> 70%), the accuracy of the phase increment and the appearance of the FFT of the phase-corrected data.

Simulation Experiments #1 - In a first set of experiments sequences of the form 90(P_{EX})-[170(P) –echo-170(-P) –echo- $]_{32}$ were investigated (*brackets denote pulse phase*). This corresponds to 1D imaging with two coils with equal and opposite phase gradients. Reconstruction was by complex conjugation of alternate echoes followed by FFT. *Results***:** As expected, the CPMG condition (P_{EX}=90^O, P=0^O) provides excellent performance (*Fig.1c*), however very closely related sequences such as (P_{EX}=90^O, P=5^O) and (P_{EX}=90^O, P=-5^O) in the in two narrow bands very close to and on neither side of CPMG perform poorly with rapid loss of echo intensity (*Fig.1d*). These behaviours correspond well with experimental results (0.2T) where signal drop-out was observed surrounding a bright line (*Fig.1a*). This class of sequences perform well for the range P= 15^O…70^O, for a wide range of excitation pulse phases.

Simulation Experiments #2 – In a second set of experiments we aimed to avoid the problem regions adjacent to the CPMG condition and thus extend the range of useable P values (corresponding to a larger artifact-free FOV). Sequences of the form: *90(0) [170(-P) echo 170(P+90) echo]$_{32}$* were found to satisfy these requirements. However, a different reconstruction echo phase cycle is required, consisting of multiplying the real and imaginary echo components by (-,+), (+,+), (+,-), (-,-) in a 4-echo cycle prior to FFT. *Results:* Artifact severity is reduced and a wider range of acceptable pulse sequences [P range > -45^O…+45^O]. The reconstruction method works for all sequences in the set.

Simulation Experiments #3: More sequence types become feasible by use of a more general reconstruction method. Data from sequences of the form: *90(P_{EX})-[170(P_A+d1) e 170(-P_A-d2) e 170(P_A+d3) e 170(-P_A-d4) e $]_{16}$* can be reconstructed by applying a phase correction for the d terms followed by complex conjugation of alternate echoes and FFT. The phase correction is performed using a phase term for the e^{th} echo: *exp[-2i Sum(d_E)]* where the sum is over 1 → e. *Results*: the phase correction scheme was verified. Results of the performance of this wider class of sequences will be presented.

Conclusions: Simulations of the 1D TRASE RF imaging sequence correspond well with experimentally observed image artifacts and have enabled improved sequences to be designed. More general reconstruction methods allow greater freedom in sequence design and optimization. Characterization of sequence performance for off-resonance and B1 inhomogeneity will allow rational specification of transmit coil array design parameters (efficiency / refocusing pulse length, B1 homogeneity, phase gradient strength).

References: 1) King SB, Yin D, Thingvold S, Sharp JC, Tomanek B. Proc ISMRM Seattle; 2006. p 2628; 2) King SB, Latta P, Volotovskyy V, Sharp JC, Tomanek B. Proc ISMRM Berlin; 2007. p 680; 3) Sharp JC, King SB, Yin D, Volotovskyy V, Tomanek B. Proc ISMRM Toronto; 2008. p 1083; 4) Sharp JC, Scott B. King, D.Yin, V. Volotovskyy, B. Tomanek, Proc ISMRM Toronto, May p.829 2008; 5) Sharp JC, King SB Magn. Reson. Med. (submitted). 6) King SB, Latta, Volotovskyy V, Sharp JC, Tomanek B. (this meeting).

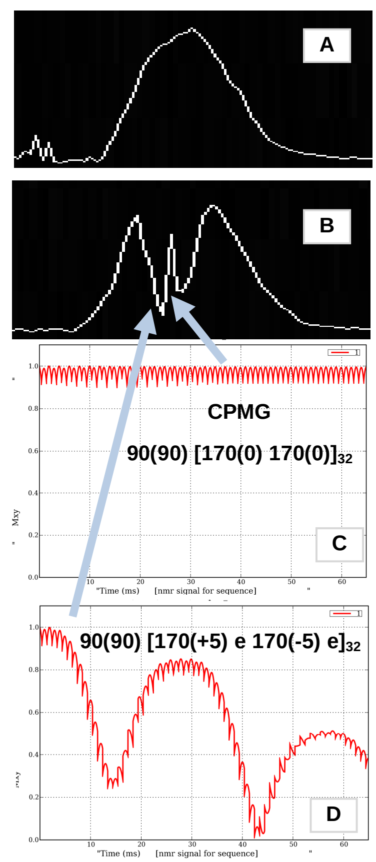

Fig1. A,B Experimental 1D profiles (0.2Tesla, 5cm diam. vial). **A)** Clean profile; **B)** Artifact with loss of signal surrounding bright line (CPMG condition) at center; **C)** simulated CPMG echo train (N=64); **D)** simulated 90_{90} -[180_{+5} $180_{-5}$$]_{32}$ echo train – corresponds to adjacent areas of signal loss.