# Multiecho Sequences with Variable Refocusing Flip Angles: Optimization of Signal Behavior Using Smooth Transitions between Pseudo Steady States (TRAPS)

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**Abstract**
The paper presents a strategy for optimization of refocusing flip angles in TSE-sequences based on the insight, that the signal behavior in the optimised static pseudo steady state for a given refocusing flip angle allows a smooth variation of echo amplitudes by continuous variation of the refocusing flip angles. This allows to produce echo trains with high signal intensities at the time of the relevant echoes encoding for the k-space center with less signal and therefore RF-power for the other echoes. Savings in SAR can be as high as a factor of 10 for HASTE-sequences and 50-75% for segmented scans.

## Introduction

The purpose of this paper is to demonstrate, that the static pseudo steady state in a suitably prepared multiecho experiment (1-3) not only delivers the maximum signal for a given refocusing flip angle, but also shows a very stable behavior against further flip angle variations. This allows to freely vary refocusing flip angles and therefore to optimize the echo amplitudes along an echo train. For a given total RF-power the sampling efficiency will thus be optimized, which is of particular interest for high field applications, where SAR sets severe limitations to multiecho-imaging.

## Methods

Fig.1A demonstrates the echo behavior with respect to a modification of the refocusing flip angle. It is demonstrated, that further signal modulations and a suboptimal pseudo steady state ensues compared to the use of the higher flip angle throughout.

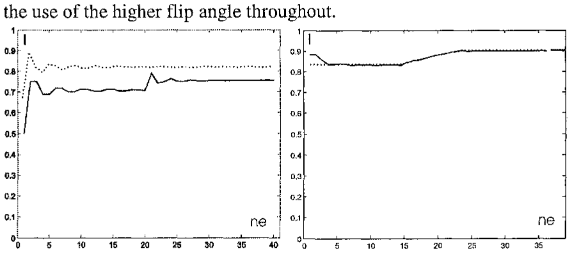


Fig.1 **(A)** Signal amplitude in a multiecho experiment with a constant refocusing flip angle of 90° over the first 20 echoes followed by 110° over the rest of the echo train compared to the use of 110° throughout (dotted line) **(B)** Transition from the static pseudo steady state for 90° by slowly incrementing the flip angle to 110° maintains the full echo intensity.

The signal behavior is markedly different, if spins are first brought into the static pseudo steady state (sPSS) (2,3). As shown in Fig.1B, changing the refocusing flip angle after reaching the sPSS will not only avoid signal modulations, but also lead to a signal intensity, which is very close to the maximum achievable steady state signal for the final refocusing flip angle. Fig.2 demonstrates, that the relative signal change ΔI compared to the maximum attainable signal is smaller than 1% for changes in the refocusing flip angle by +- 20° over a broad range of flip angles.

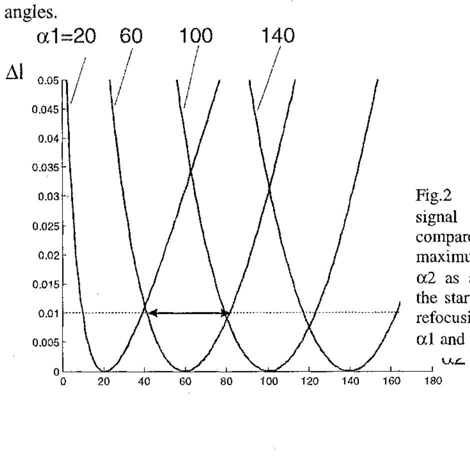


Fig.2 Penalty in signal intensity ΔI compared to the maximum signal at α2 as a function of the starting and final refocusing flip angles α1 and α2.

This very benign signal behavior can be used to tailor the refocusing flip angles such, that high flip angles are used only for the 'important' echoes encoding for the center of k-space as shown in Fig.3. It is remarkable to note, that signal can be made to grow back to the full amplitude after the initial drop to less than 50%.

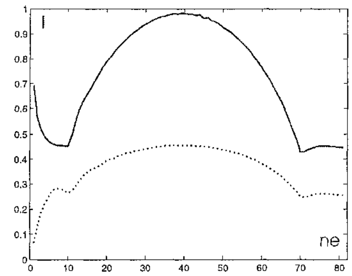


Fig.3. Signal intensity for a linear increase of the refocusing flip angle from 30° to 180° and back again after preparation with a sequence of refocusing pulses with flip angles 112,5°, 59,5°, 44,5°, 37° over the first 4 refocusing periods compared to preparation with constant flip angles (dotted line).

## Experimental

Experiments were performed at a 1.5 T system (Siemens Sonata) as well as with a 3T system (Siemens Allegra) with 40 mT/m gradients. A TSE-sequence with echo-spacing of 10 ms and echo train length 15-37 was used as the basis of the TRAPS-implementations.

## Results

Fig.4 demonstrates, that TRAPS produces images of comparable quality to a fully refocused TSE-sequence at considerably reduced SAR compared to a fully refocused sequence. Signals from parenchyma with T1>T2 is even increased due to the contributions of stimulated echo pathways.

A B C

Fig.4. TSE-image acquired at 3T with 180°-refocusing flip angle throughout (SLTH 5mm, TE/TR=127/ 3750 ms, ETL 27, 256x256) (left) compared to TRAPS images with a linear increase of the refocusing flip angle from 90°-180°(middle) resp. 40°-180°(right) from echo 6-11 and back to 40° over echoes 13-18. The relative SAR is 33%(B) and 26%(C) compared to A.

## Conclusions

TRAPS allows to acquire TSE-images at considerably reduced SAR without penalty in S/N. TRAPS can be combined with the hyperecho mechanism (4) in order to produce fully symmetric signals. It also allows multiple transitions to the full signal i.e. for multicontrast-TSE with shared echoes.

**References**
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