# Modified Turbo Spin Echo sequence for PRF based thermometry

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**Introduction:** The goal of the present work is to show the feasibility of proton resonance frequency (PRF) shift based thermometry using a modified Turbo Spin Echo (modified TSE) sequence. The TSE sequence is known to have high specific absorption rate (SAR) that may cause tissue heating. It's therefore of interest to try to measure temperature with the TSE sequence. Despite the obvious advantage of TSE in terms of speed and high signal-to-noise ratio (SNR), the implementation of imaging procedures that rely on induced phase encoding (flow, chemical shift) are more difficult because of the required maintenance of the Carr-Purcell-Meiboom-Gill (CPMG) conditions in TSE. In this work, we present a modified TSE sequence to generate phase maps, in which the proton resonance frequency shift is detected.

**Theory:** In principle, any spin echo-based technique can be used to measure temperature if the readout is made asymmetric such that the center of the readout echo is shifted away from the time of the spin echo. In that case, the frequency offset due to the temperature change will cause non-zero temperature dependent phase at the time of the gradient echo. This phase shift $\Delta\boldsymbol{\phi}$ will equal the frequency shift times the time offset $\boldsymbol{\tau}$, which allows the buildup of the PRF shift: $\Delta\boldsymbol{\phi} = \gamma*\alpha*B_o*\boldsymbol{\tau}*\Delta T$

The proposed sequence, depicted in Figure 1, is a modified TSE sequence to meet that requirement.

**Methods:**

***Calibration experiments***. Calibration experiments were performed by continuously acquiring images from a heated agar gel phantom during the cooling phase. The phantom was uniformly heated up to $70^0$C. To validate our MR measurements, fiberoptic temperature probes (AccSens, OpSENS Inc., Quebec, Canada) were positioned in the agar phantom during acquisition. All MR imaging was performed using a 12 channel phased array receive coil on the Siemens TIM Trio 3T MRI scanner (Siemens Medical Solutions, Erlangen, Germany) with TR/TE/ $\boldsymbol{\tau}$ = 3000/61/ 1.74 ms, $180^0$ refocusing pulse, turbo factor of 129, image matrix = 256x129 and 2.4x1.2x3 mm resolution. Figure 2 shows a plot of phase change versus temperature change from a 5x4 voxel ROI near the temperature probe.

***Heating experiments***. The goal of the heating experiment was to determine the temperature change induced by the high SAR of the modified TSE within a phantom. For this purpose, a 2 liter phantom was made with the following recipe: 1.5 liter of $H_2O$, 160 ml of n-propanol, 7.2 g of NaCl, 2.5 g of $CuSo_4$, and 56 g of agarose. The above solution has a conductivity of 0.008 S $cm^{-1}$ which satisfactorily mimics the conductivity properties of most tissues [1]. A 5.5x5.5 cm coil loop taped against the side of the phantom was used to focus RF energy from the transmit coil into the phantom near the coil loop. MR images were acquired with the same parameter sets as the calibration experiments except: the image matrix was 256x126, the turbo factor was 7 and the scan time was 30 min and 26 sec for 32 measurements (figures 3 and 4).

**Results**: The calibration curve shows a good correlation between the fiberoptic reading and the phase change. The apparent PRF-thermal coefficient α was found to be 0.014ppm/ $^0$C. This relatively high value of α can be explained by the relatively low value of the time offset $\boldsymbol{\tau}$ [2]. Since $\boldsymbol{\tau} < T^*_2$ of our phantom, we predicted a relatively noisy temperature map (see figures 5 and 6).

**Conclusion**: Although, the proposed modified TSE sequence is in an early development stage, we have shown that this sequence can be used to monitor temperature and could be used to quantify heating effects in suspect TSE studies. Temperature sensitivity improvement of the modified TSE sequence and a full comparison with the available thermometry sequences will be investigated in future work.

**References**: [1] Joseph G. Och et Al. Medical Physics, Vol. 19, Issue 1, 1992, [2] Robert D. Peters et Al. MRM 43:62-71(2000).

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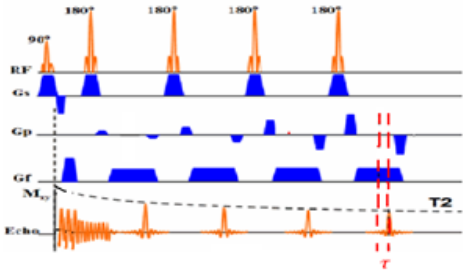


**fig 1**: *Modified Turbo Spin Echo sequence with echo shifted by* $\boldsymbol{\tau}$ *away from the time of the spin echo.*

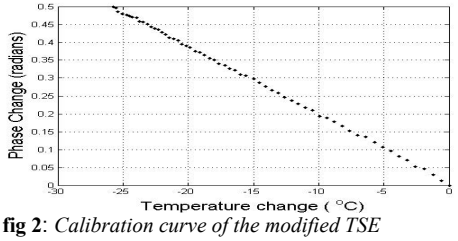


**fig 2**: *Calibration curve of the modified TSE sequence. Plot of MR phase vs Temperature reading from the fiberoptic probes.*

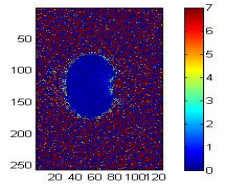

**fig 3**:*Temperature map of a single slice after the first measurement.*

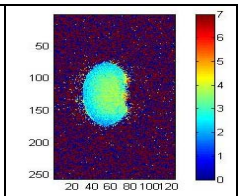

**fig 4**: *Temperature map of single slice at last measurement.*

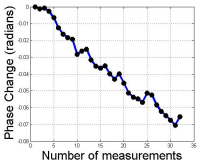


**fig 5**: *Plot of the ROI (16x11 voxels)mean value chosen within the phantom vs number of measurements.*

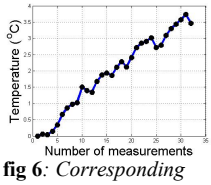


**fig 6**: *Corresponding temperature change within ROI vs number of measurements.*