A NEW TIME SHIFTED FAST SPIN ECHO THERMOMETRY SEQUENCE

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Introduction: MR-guided Focused Ultrasound (MRgFUS) is used to treat noninvasively many brain disorders, e.g. essential tremor, psychiatric disorders and tumors. Currently gradient echo (GRE) is used for thermometry imaging using the PRF shift (1). In this abstract we present a new thermometry sequence which is based on Fast Spin Echo (FSE). This sequence is faster, not sensitive to field inhomogeneity and provides higher temperature signal-to-noise ratio (TSNR).

Theory: Fig. 1 shows an FSE sequence. Each echo in the train can be divided into two pure echoes (2): An even echo that experience an even number of phase inversions and an odd echo with odd number of inversions. Consequently, a phase φ before the first refocusing pulse phase-shifts each even echo by φ and each odd echo by -φ. These echoes are separated by running two FSE shots: the phase of the 90° pulse is 0° and 90° in shot 1 and 2 respectively. Images $\mathbf{I_{even}}$ and $\mathbf{I_{odd}}$ from all the even and odd echoes in the train are reconstructed by adding and subtracting the signals from the two shots (2). The PRF shift is calculated from the phase difference 2φ between I_{even} and I_{odd}. The pulse sequence we use (Fig. 1) is a conventional FSE where the 90° pulse is shifted in time by T sec from the first refocusing pulse. The phase ΔΦ between the echoes due to a frequency shift Δf (PRF shift) for FSE and GRE is given by Eq. [1] and [2] respectively.

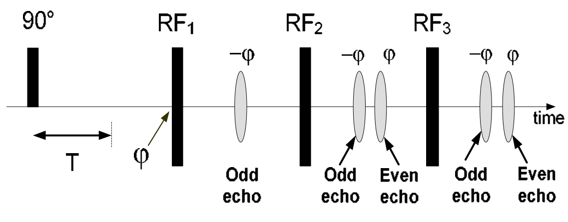

Fig. 1

$$\Delta\Phi\,(\mathrm{FSE}) = 4\pi \cdot \Delta f \cdot T \quad [1]\,; \qquad \Delta\Phi\,(GRE) = 2\pi \cdot \Delta f \cdot TE \quad [2]$$

To remove background phase a "cold" reference image is acquired before heating and its phase is subtracted from the phase of the "hot" images.

Data Processing: Fig 2 shows the simulated even and odd echo amplitudes vs. echo number in the train. Clearly there are oscillations. When I_{even} and I_{odd} are added we obtain the smooth CPMG signal (3). Since the oscillations are the same (up to a global phase) for the reference image and the "hot" images, we calculate the oscillatory part of signal using the reference image and subtract it from the "hot" images. To obtain a smooth decay we 1) ignore the first three echoes in the train. 2) Subtract the oscillatory signal from the images. The simulated smooth signal is shown in Fig. 3b. The data processing steps are a) separate the reference images and the "hot" images into even and odd echoes. b) Subtract the (low resolution) reference phase from the phase of "hot" images. Repeat for both even and odd echoes. c) Remove the oscillatory signal as explained above. d) Calculate the phase difference 2φ between the processed even and odd echoes.

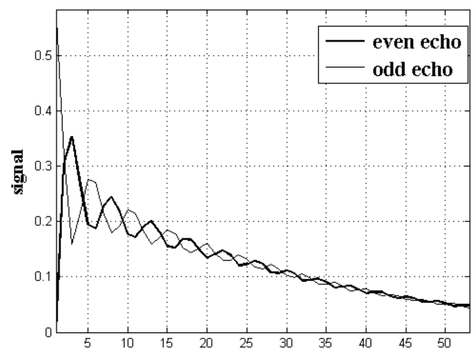

Fig. 2

Data Acquisition: To enable a long echo train we modulate the RF flip angles along the echo train. The optimization technique is similar to 3D Cube (4). The ky lines are acquired in a centric order, where the first acquired echo (echo 4) is at ky = 0. The even and odd echo amplitudes vs. ky for an echo train of 53 echoes is shown in Fig. 3a. The smooth decay after removing the oscillations is shown in Fig. 3b.

Results: We compared GRE and FSE for TSNR and imaging speed by running the FSE sequence with parameters that are as close as possible to the GRE parameters. The GRE parameters are: 128 x 256 matrix, TR/TE = 26/12 msec with 5.6 kHz receiver bandwidth, 4 mm slice, 26 cm FOV, scan time of 3.4 sec for 1 slice and 10 sec for 3 slices. The FSE imaging parameters are: 100 x 256 matrix with rectangular FOV of 20 x 26 cm. Echo train of 53 echoes with 50 acquired echoes, echo space (esp) of 6.1 msec and 40 kHz receiver bandwidth. 4 shots are required to sample 100 ky lines because each echo train is acquired twice (phase cycling). The total scan time to scan 3 slices is about 4.2 sec. To compare TSNR of both sequences we acquired two scans with a center frequency difference of 15 Hz using transmit/ receive Head coil at 1.5T with a 17 cm diameter spherical phantom (T1/T2 = 200/130 msec). TSNR is the ratio between the mean and r.m.s. of an ROI centered on the phase-difference image. The results are shown in Table 1. The mean phase of both sequences is in agreement with [1] and [2]. For FSE we obtain significantly higher TSNR by increasing T with negligible increase in scan time.

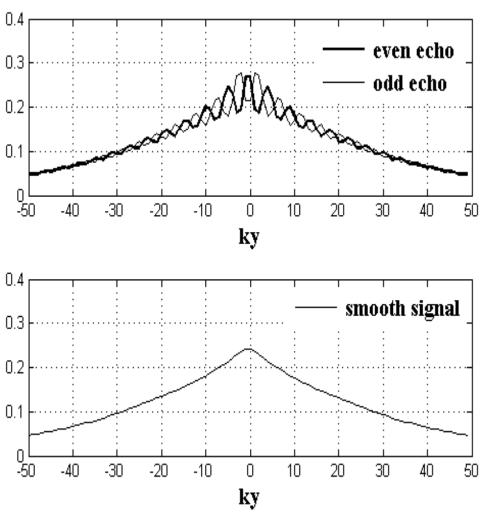

Fig. 3

Discussion: The advantages of the FSE sequence over GRE are: a) it is not affected by b0 inhomogeneity because the phase between ky lines is fully refocused. b) The TSNR can increase significantly by increasing T with negligible increase of scan time. c) 3 slices can be scanned during heating, which is essential for MRgFUS safety. A drawback of the method is the high SAR.

sequence	T or TE (msec)	TSNR	Scan time, sec	slices
GRE	TE = 12	38	3.4	1
FSE	T = 12	41	4.1	3
FSE	T = 20	65	4.2	3
FSE	T = 30	80	4.3	3

Table 1: comparison between FSE and GRE

References: (1) IshiharaY et al. Mag. Res. Med. 1995;34: 814–823. (2) Y. Zur and S. Stokar. J. Mag. Res. 1987: 71:212-228. (3) D. G. Norris et al Mag. Res. Med. 1992; 27: 142-164. (4) R. F. Busse et al. Mag. Res. Med. 2008: 60: 640-649.