A technique to eliminate artifacts in 3D Fast Spin Echo Imaging

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Introduction: Fast spin echo (FSE) or RARE (1) imaging, plays a central role in clinical imaging and high resolution T2 weighted imaging in particular. High resolution 3D FSE with flip angle modulation (2) is ideally suited for these applications due to high T2 contrast and the ability to reformat the data in any desirable plane. However, violation of the CPMG condition (due to eddy currents and gradient imperfection) within the volume of interest results in image artifact. This artifact is very prominent for high T2 fluids at off-center locations such as shoulder and wrist. Therefore a reliable artifact-free 3D FSE imaging remains a challenge. In this work we present a technique to overcome this problem using a post processing method applied in conjunction with a two-excitations approach (3).

Theory: Fig. 1 shows an FSE sequence. Each echo in the train can be divided into two pure echoes (3): 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 as shown in Fig. 1. If $\varphi \neq 0$ (i.e. CPMG condition is violated) artifacts are created by the spatially varying phase difference 2φ(r) between the echoes. To remove this artifact both echoes are separated (3) by running two FSE shots with phase cycling. Images I_{even} and I_{odd} from all the even and odd echoes in the train are reconstructed. The CPMG artifact is removed by combining I_{even} and I_{odd} constructively by eliminating the phase difference 2φ(r) between them as in Eq. [1].

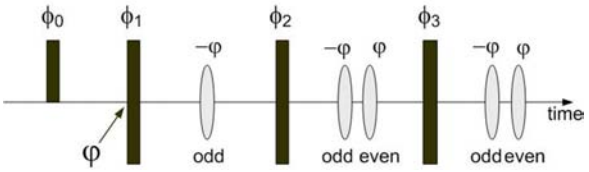
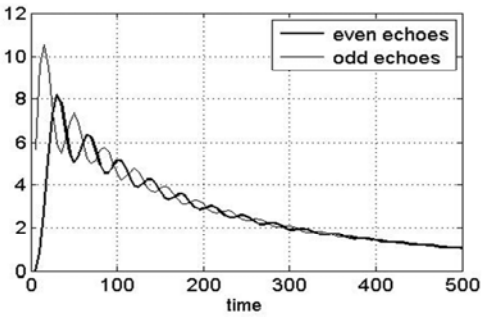


Figure 1

$$I = I_{even} + I_{odd} \cdot \exp[-i2\varphi(r)] \qquad [1]$$

The time domain signal of $I_{even}(r)$ and $I_{odd}(r)$ is shown in Fig. 2 (left). Due to the oscillations the Point Spread Function (PSF) in Fig. 2(right) causes blurring and duplication of image edges. These artifacts are clearly visible in the phantom image in Fig. 3 (left). Hence Eq. [1] does not provide an acceptable solution.



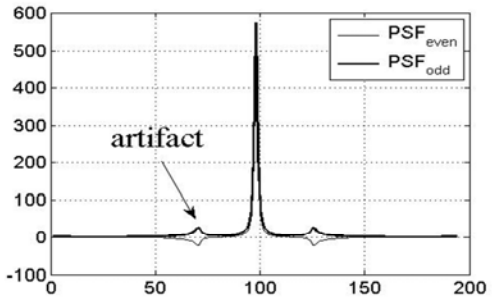
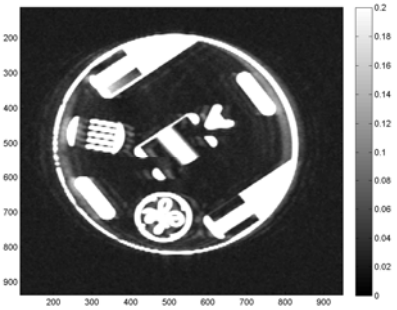


Figure 2
Left: Time domain signal of even echoes and odd echoes. The oscillations cause artifacts.
Right: PSF of even and odd echoes.

Method: The phase φ(r) in Eq. [1] should be applied only to the central lobe of the PSF in Fig. 2. The two side lobes must remain untouched, such that when the even and odd echoes are added they cancel each other. Since φ(r) is slowly varying, this can be achieved by spatially filtering I_{even} and I_{odd} with a low pass Gaussian filter. This broadens the PSF such that the central and side lobes in Fig. 2 become indistinguishable. The phase difference between the filtered I_{even} and the filtered I_{odd}, denoted $\varphi_1(r)$, affects only the central lobe of the PSF in Fig. 2. The final image is reconstructed using Eq. [2], where I_{even} and I_{odd} are the original unfiltered images. Since $\varphi_1(r)$ does not affect the side lobes of the PSF they cancel out and the artifact in Fig. 3 (left) is removed, as shown in Fig. 3 (right).

$$I = I_{even} + I_{odd} \cdot \exp[-i2\varphi_1(r)] \qquad [2]$$



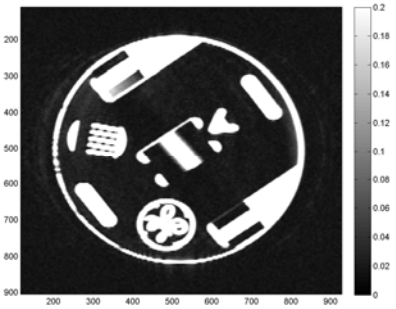


Figure 3
Left: Phantom image from a reformatted 3D dataset reconstructed using Eq. [1]. The edge blurring and duplication artifact is caused by the PSF in Fig. 2 right.
Right: Image of the same dataset reconstructed with Eq. [2].

Discussion and conclusion: The method presented here is robust with excellent artifact-free image quality, but it comes at a cost of doubling the scan time because two FSE trains are used. To reduce scan time we use Half Nex acquisition and/or increase the parallel imaging acceleration factor.

References: (1) J. Hennig et al Mag. Res. Med. 1986; 3, 823 - 833. (2) R. Busse et al Mag. Res. Med. 2008; 60, 640 - 649. (3) Y. Zur et al J. Mag. Res. 1987; 71, 212 - 228.