Detection of Current-induced Magnetic Field Fluctuation Using 3D Balanced SSFP CINE Sequences

Q. Peng[1], P. Weatherall[1], J. Chia[2], J. Wang[1]

[1]Radiology, University of Texas Southwestern Medical School, Dallas, Texas, United States, [2]Philips Medical System Inc., Dallas, Texas, United States

Introduction

The detection of electrical current in the magnetic field using MRI has recently gained more attentions for its potential applications in detecting neuronal current activation directly in human brain [1, 2, 3]. Previously, it was shown that the weak magnetic field change could be detected using magnetic resonance phase imaging and different MR sequences such as spin echo [4], SE or GE EPI was employed [1,2,3]. These approaches, however, suffer from low temporal resolution and/or low image quality. It has been found lately that balanced Steady-State Free Precession (b-SSFP) pulse sequence is sensitive to local magnetic field change if TE is not equal to TR/2. Also, high temporal and spatial resolution can be achieved simultaneously by using 3D balanced SSFP CINE sequences. We present here the feasibility of a new method to detect weak magnetic field fluctuation induced by alternating currents with 10 ms temporal resolution using this b-SSFP sequence.

Theory and Simulation

It has been shown that b-SSFP has a unique phase evolution profile that is dependent on the selection of TE [5]. For TE=TR/2 the signal has almost zero phase for off-resonance frequencies ranging between ±1/(2TR). In this situation, the phase evolution is similar to that of an SE sequence for limited range of dephasing angle between $\pm 0.8\pi$ in each TR. However, the b-SSFP sequence shows a linearly increasing T_2^* sensitivity for varying TEs around TR/2. The relative phase sensitivity of b-SSFP to off-resonance can be approximated as: θ_d/θ_{TR}=TE/TR-1/2, where θ_d is the phase detectable by a b-SSFP sequence, and θ_{TR} is the dephasing angle within a TR. Depending on the specific T1 and T2 of the imaged tissue, the relative phase sensitivity varies slightly from this approximation. A simulated relative sensitivity as a function of TE is shown in Fig. 1. We believe that current detection in MRI can be performed using these properties of b-SSFP.

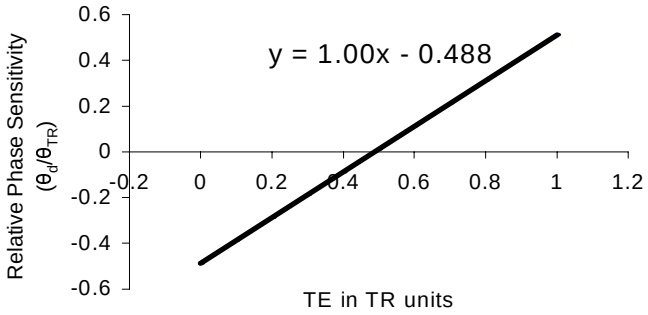

Fig. 1. Simulated relative phase sensitivity of b-SSFP sequence to dephasing in each TR as a function of TE. T1/T2/FA = 253/210/80° was used in the simulation. Note that the intercept point on x-axis is 0.488, which means if TE = 0.488TR, b-SSFP sequences are not sensitive to off-resonance.

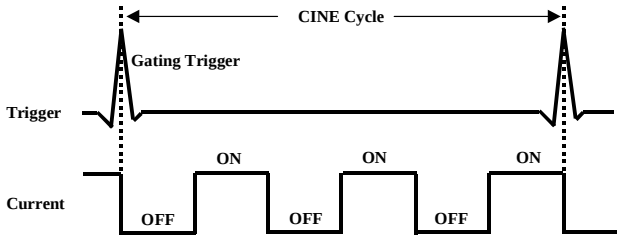

Fig. 2. Schematic diagram of experimental timing. Each CINE cycle was 300 ms, and each current "ON" or "OFF" period was 50 ms. Since TR was set to 10 ms, a total of 30 CINE phases was obtained.

Methods and Results

Experiments were performed on a 1.5T Philips Intera MR scanner with 33mT/m and 150T/m/s performance using a 14 cm diameter surface coil. A cylindrical phantom (diameter=8cm, height=7cm) filled with 4 mM $CuSO_4$ water solution was used. A U-shaped insulated copper wire (0.36 mm diameter) with a straight base was immersed in the solution, with the direction of the two sides of the wire parallel to main magnetic field B_0, and the 4 mm long base segment perpendicular to B_0. The segment of the wire perpendicular to B_0 was centered in the surface coil to get optimal SNR. A 3D balanced SSFP CINE protocol was performed with TR/TE/FA = 10/1.96/80°, FOV = 12.8 × 9.6 cm^2, slice thickness = 2 mm, matrix = 64 × 48, and NEX = 1. A retrospective cardiac gating was utilized in the sequence, with gate width = 10 ms, and 30 phases (or "cardiac phases") were obtained for the 300ms CINE cycle. 5 axial slices centered at the wire tip were imaged, resulting in 150 total images for the scan. The schematic diagram of the synchronization is as shown in Fig. 2. The total scan time of this sequence was 1:17 min. For comparison, a single-shot GE EPI sequence was also employed to detect the first "ON" pulse (changed to 10 ms duration) in each CINE cycle, with TR/TE/FA=150/40/60°, and same matrix, FOV, slice number, slice thickness and positioning as in the b-SSFP sequence. Magnitude and phase comparison images are shown in Fig. 3. The detected phase changes of b-SSFP and GE EPI sequences are presented in Fig. 4.

Discussion and Conclusion

Although the sensitivity of b-SSFP sequence is about 1/3 of that of EPI sequence in our experiment, SNR of b-SSFP sequence is more than 3 times higher than that of EPI sequence (280 vs. 64.6), as shown in Fig. 3. As standard deviation of the phase noise σ_φ is given as $\sigma_\varphi \sim 1/SNR_M$ [6], our preliminary results show an improved phase change to noise ratio by using b-SSFP sequence. By combining CINE technique with b-SSFP, a temporal resolution of 10 ms or less can be achieved. It is also possible to achieve high spatial resolution simultaneously by simply increasing matrix size. We have shown that using 3D b-SSFP sequences may be a feasible alternative for the detection of direct neuronal current response of human brain compared with EPI approaches with the inherent advantages such as higher SNR, less geometric distortion, lack of aliasing artifacts, and are inherently flow and motion insensitive.

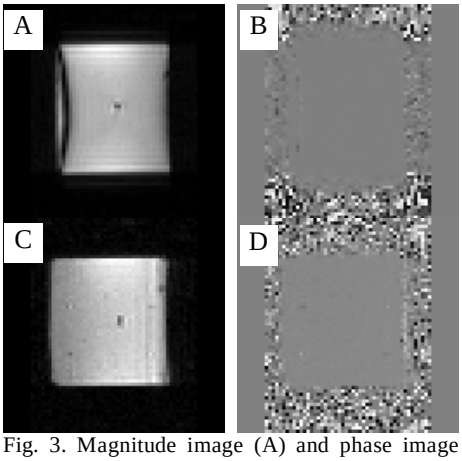

Fig. 3. Magnitude image (A) and phase image (B) of the b-SSFP sequence. The banding artifact is clearly shown. Magnitude image (C) and phase image (D) of the EPI sequence.

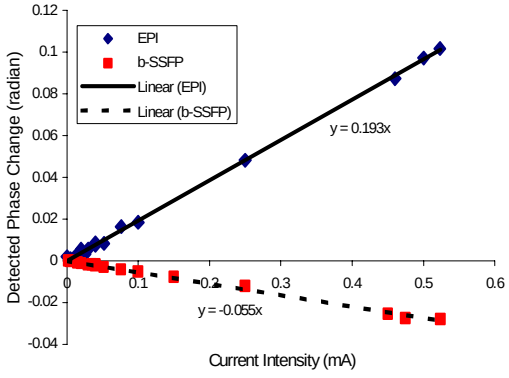

Fig. 4. The detected phase contrasts with current "ON" and "OFF" for one of the pixels close to the wire using GE EPI and b-SSFP sequences. It is clearly shown that EPI sequence has higher phase sensitivity than b-SSFP sequence. The detected relative phase sensitivity for b-SSFP is -0.055/0.193=–0.285, and the simulated results from Fig. 1 is -0.292. The experimental/theoretical results agree well.

References

1. Kon, et al. MRM, 50: p40-9, 2003
2. Bodurka, et al. MRM, 47: p1052-8, 2002
3. Bodurka, et al. JMRI, 137:p265-71, 1999
4. Joy, et al. MRI, 7:p89-94, 1989
5. Scheffler, et al, MRM, 49: p295-7, 2003
6. Scott, et al, MRM, 97: p235-54, 1999