# Separating FID and echo contribution in pass-band bSSFP fMRI with multiple-phase angle cycling

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## Introduction

Pass-band bSSFP is a promising tool for high-resolution fMRI, but its signal sources have been unclear especially at high field. The bSSFP signals are summation of free induction decay (FID) component and echo components from multiple RF pathways. Multiple TR and TE experiments have been used in previous studies to understand contributions of FID and echo components to the signals of bSSFP fMRI (*1,2*). Although this approach provides useful information, an alternative approach is to acquire datasets using multiple phase cycling angles which enable separation of FID and echo components in the Fourier domain (*3*). In this study, we performed fMRI experiments at multiple phase cycling angles with the aim to separate the FID and echo components based on Fourier analysis. To help to identify the bSSFP signal sources, we utilized the notion that FID component would have larger draining contribution (i.e., intracortical or surface veins), whereas echo component would be more spatially localized because of stronger $T_2$ contribution. MR venogram was used to confirm the location of the veins on the same animals. This approach of multiple phase cycling angles has the potential to provide new insights into the signal sources of pass-band bSSFP fMRI.

### Material and Methods

Three male Sprague-Dawley rats weighing 300–450 g were used with approval from the IACUC. The rats were initially anesthetized and then intubated for mechanical ventilation. The femoral artery and femoral vein were catheterized for blood gas sampling and for fluid administration, respectively. After the surgical procedure, isoflurane level was maintained at 1.4%. The head of the animal was carefully secured to a home-built cradle. Rectal temperature was maintained at 37 ± 0.5 °C. Ventilation rate and volume were adjusted based on blood gas analysis results. Electrical stimulation was applied to either the right or left forelimb
b using two needle electrodes. Stimulation parameters for activation studies were: current = 1.2–1.6 mA, pulse duration = 3 ms, repetition rate = 6 Hz, stimulation duration = 15 s, and inter-stimulation period = 3 min (*4*).

All experiments were carried out on a Varian 9.4 T / 31-cm MRI system with an actively-shielded gradient coil of 12-cm inner diameter. A homogeneous coil and a surface coil were used for RF excitation and reception, respectively. Eight pass-band bSSFP fMRI studies were performed: four with TR / TE = 20/10 ms and the remaining four bSSFP studies with TR / TE = 10/5 ms. Each set of four bSSFP studies was composed of four different phase cycling angles of 0°, 90°, 180°, and 270°. Other scan parameters common to all the fMRI studies were: matrix size = 256 × 192, FOV = 2.4 × 2.4 cm$^2$, number of slice = 1, slice thickness = 2 mm, and flip angle = 16°. Twenty four images were acquired for each fMRI study; eight during prestimulus baseline, four during stimulation, and twelve during the poststimulus period. Resonance frequency was recalibrated before each fMRI study to minimize $B_0$ drifting effects. The eight bSSFP fMRI studies composed one full set and each full set was repeated 15 to 25 times for averaging. BOLD microscopy was performed with a 3D RF-spoiled gradient-echo pulse sequence, as described previously (*5*), with imaging parameters of TR = 40 ms, TE = 20 ms, matrix size = 256 × 192 × 128, FOV = 2.4 × 2.4 × 1.2 cm$^3$, NEX = 2, and total scan time = 18.4 min.

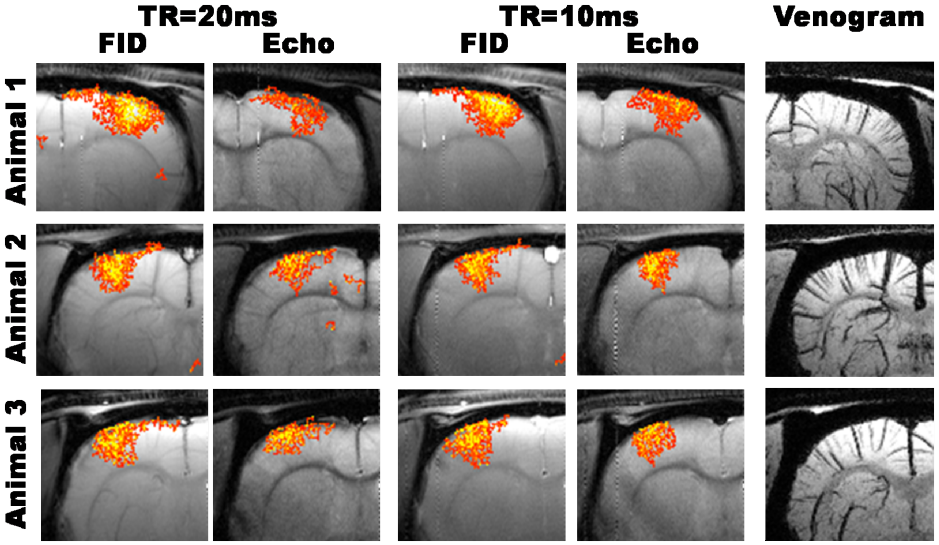


FIG. 1. **Functional maps of FID and echo components** extracted from the multiple phase cycled bSSFP fMRI. The fMRI maps are displayed for all three animals as T maps with maximum and minimum T values of 8 and 1.2, respectively, and minimum cluster size of 15. TR values and each component are displayed on top of the figure.

## Results and Discussion

The multiple phase-cycled bSSFP fMRI maps could be separated into FID and main echo components with Fourier analysis and the resulting images are shown for all animals tested in Fig. 1. Functional map from the FID component generally showed higher sensitivity than that from the echo component. However, the functional map from FID component showed stronger correlation with intracortical veins as well as cortical surface veins, at both long and short TR values (Fig. 1). The bSSFP fMRI signals from the main echo component was about 30% and 50% of those from the FID component at TR/TE of 20/10 ms and 10/5 ms, respectively. Our results suggest that although FID component showed stronger fMRI signals than the main echo component, the main echo component was not negligible under our experimental conditions, in contrast to the previous study reporting that FID component dominated the bSSFP signal decay and, thus, fMRI contrast (*1*).

## Conclusion

Multiple phase cycled bSSFP fMRI datasets could be separated into FID and main echo components based on Fourier analysis. FID component showed stronger fMRI signals than the main echo component, but showed stronger correlation with both intracortical veins and cortical surface veins. The fMRI signal from the main echo component could contribute up to half of that from the FID component, and thus should not be ignored in interpreting pass-band bSSFP fMRI signals.

### References

1. Zhong et al. Magn Reson Med 57:67-73 (2007). 2. Miller et al, Neuroimage 37:1227-1236 (2007). 3. Zur et al, Magn Reson Med 16:444-459 (1990). 4. Kim et al, J Cereb Blood Flow Metab 27:1235-1247 (2007). 5. Park et al, Magn Reson Med 59:855-865 (2008).