Spatial and spectral analysis for a radial sapmling balance SSFP for fMRI

R. F. Lee[1], J. Xu[2], K. Prabhakaran[3], and M. Arcaro[4]

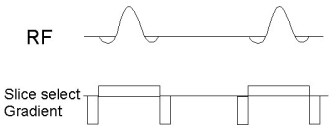
[1]Neuroscience Institute, Princeton University, Princeton, NJ, United States, [2]Siemens Medical Solution USA, [3]Neuroscience Institute, Princeton University, [4]Psychology, Princeton University

Introduction

Using balanced SSFP sequence for fMRI provides an alternative way to measure BOLD effect (1). This method is more immune to the signal drop-out from susceptibility and image distortion and blurring in EPI. Currently most analyses related to this approach are based on the assumption that RF pulses are infinitely short and slice profiles are no concern. In this study, the steady-state is established with RF pulses that have sinc pulse shape and balanced slice selective gradient. Thus, transition band within a slice can be fully analyzed. Meanwhile, although Fourier imaging are often used for this type of studies, we developed a radial sampling sequence for balanced SSFP fMRI, whose absence of phase encoding can further reduce the TE and therefore susceptibility artifacts.

Method

1. Analysis: Solving Bloch equation for a sinc RF pulse excitation was done by the piece-wise spinor rotation introduced in Ref. (2). In the steady state shown in Fig. 1, the excitation is characterized by A(z, t) and relaxation are characterized by R and R0, where



$$A(z,\tau)=\begin{bmatrix}\alpha^{*2} & -\beta^{2} & 2\alpha^{*}\beta \\ -\beta^{*2} & \alpha^{2} & 2\alpha\beta^{*} \\ -\alpha^{*}\beta^{*} & -\alpha\beta & \alpha\alpha^{*}-\beta\beta^{*}\end{bmatrix},\ R=\begin{bmatrix}E_2 e^{-i\varphi} & 0 & 0 \\ 0 & E_2 e^{-i\varphi} & 0 \\ 0 & 0 & E_1\end{bmatrix},\ R_0=\begin{bmatrix}0 \\ 0 \\ M_0(1-E_1)\end{bmatrix}. \quad [1]$$

Here α and β are the spinors derived by dividing a sinc function to 100 pieces of rectangle, $E_1=e^{-TR/T1}$, $E_2=e^{-TR/T2}$, $\varphi=\omega$ TR, the precession angle during TR. The solution of the Bloch equation is

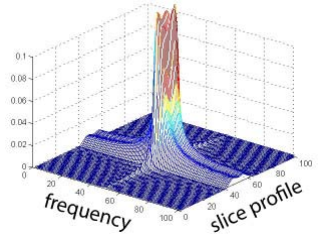
$$M_{xy}=\frac{s_0+s_1 e^{-i\varphi}}{r_0+r_1\cos\varphi+r_2\sin\varphi}, \quad [2]$$

where $s_0=-2\alpha^*\beta(1-E_1)M_0$, $s_1=2\alpha\beta(1-E_1)M_0$, $r_0=1+(\alpha\alpha^*-\beta\beta^*)E_1-(\alpha\alpha^*-\beta\beta^*)E_2^2+E_1E_2^2$, $r_1=(\alpha^2+\alpha^{*2})(1-E_1)E_2$, $r_2=i(-\alpha^2+\alpha^{*2})(1-E_1)E_2$.

2. Sequence: A radial sampling balanced SSFP was developed based on the Siemens real-time trueFISP. With voxel size of $2x2x2cm^3$ and receive bandwidth 1.5kHz/pixel, the TE is 1.61ms and TR is 3.22ms. The signal drop due to severe susceptibility in middle of brain is significantly reduced, which allow fMRI study in some areas where the signal would be diminished in the conventional EPI sequence.

Results

Figure 2 (a) and (b) are both spatial and spectral profile of the balanced SSFP with flip angle 30° and 5°. The simulation results suggest that the transition bandwidth in the middle of slice could be twice as much as the bandwidth at the edge of the slice for 5° flip angle, which suggests that the phase difference between oxyhemoglobin and deoxyhemoglobin could deviate from the predication based on the infinite short RF pulse. Note that proper RF pulse design could improve such difference. Figure 3 (a) and (b) are the images from radial sampling balanced SSFP sequence. With 3.1s acquiring six slices, they can provide 128x128 fMRI images in the brain region that signal was diminished in EPI.



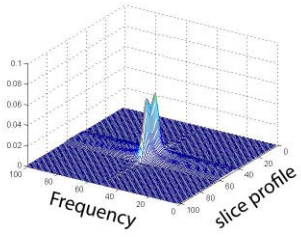
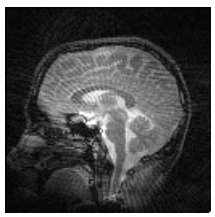


Figure 2 (a) (b)



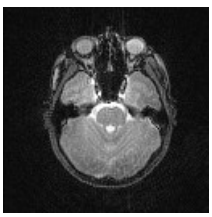


Figure 3 (a) (b)

Conclusion

The spatial and spectral analysis for the balanced SSFP sequence revealed that the transition bandwidth can be significantly different between the middle and the edge of a slice, which, so far, has not been counted for in its fMRI study. The radial sampling balanced SSFP sequence can minimize the TE so that susceptibility effect can be further reduced, which allows fMRI to study some brain region that cannot be seen in EPI.

References: (1) Miller KL, et al, MRI 50:675 (2003); (2)Pauly J., et al, IEEE trans. Med. Imag. Vol. 10, No. 1, p. 53 (1991)