Eddy current-induced artifact reduction in spiral trajectory balanced-SSFP for transition-band SSFP fMRI

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Introduction

Balanced SSFP is known to be very sensitive to any magnetization disturbance since all gradients are fully refocused in every TR and the phase accrual between RF pulses solely comes from off-resonance precession. One of the major sources for this magnetization disturbance is eddy currents that are induced from changing spiral interleaves or phase encodes. Different spiral interleaves or phase encodes induce different amounts of eddy currents that can cause additional spin dephasing (due to B0 component of the eddy currents) in balanced SSFP. As a result, serious image artifacts can be observed based on spiral interleaves or phase encodes ordering (Fig. 1a) [1]. Bieri et al. proposed an eddy currents compensation technique for RF phase-cycled Cartesian balanced-SSFP sequence [1]. Here we proposed an eddy-currents compensation method for non-RF phase-cycled 3D stack-of-spiral balanced-SSFP sequence. The formation of eddy current-induced artifacts is illustrated and a new interleaves ordering method is presented. Major applications for this method are transition-band SSFP fMRI [2] and real-time respiration compensation technique [3].

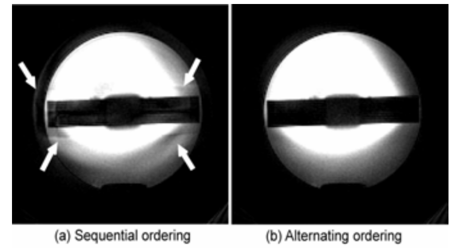

Figure 1. The non-uniform signal distribution comes from small flip angle balanced-SSFP profile. (a) Eddy current-induced artifacts. (b) The artifacts are removed by using alternating interleaves order.

Theory and Methods

In conventional balanced SSFP where RF phase cycling is utilized, the sequential phase encoding order in Cartesian or rotational interleaf order in the interleaved spiral trajectory (Fig. 3a,c) mitigates the eddy current-induced artifacts. The additional spin dephasing introduced from the eddy currents of the previous phase encode or spiral interleaf is cancelled out by the similar amount of dephasing from the next phase encode or spiral interleaf. This is because the adjacent phase encodes or spiral interleaves have a very small amount of magnetization change and the RF phase cycling shifts the direction of the induced eddy currents in every TR (Fig. 2a). Therefore no significant artifact can be observed. However, in transition-band SSFP fMRI, where small-flip-angle balanced SSFP with no RF phase cycling is used, the eddy currents induced from the sequential ordering cause serious artifacts in the image (Fig. 1a). In the sequential ordering scheme, since the RF no longer flips the dephasing direction of the eddy current-induced magnetization, the amount of spin dephasing is piled up until the phase encode or spiral interleaf magnetization goes to the opposite direction (Fig. 2b,c). This additional dephasing causes imaging artifacts as shown in Fig 1a. Hence, a new phase or interleaves ordering scheme is required to remove the artifacts. One simple and effective method is named as the 'alternating spiral interleaves (phase encodes) ordering'. This method pairs the opposite polarity spiral interleaves (phase encodes) and sequences them next to each other (Fig. 3b,d). These two opposite interleaves (phase encodes) create opposing eddy currents that will cancel themselves out in every other TR. As a result, the additional spin dephasing effect does not persist anymore (Fig 2d). In the real-time respiration compensation method [3], this alternating order is critical in measuring a reliable respiration-induced resonance offset. Since the respiration-induced resonance offset is measured from the phase of FID, the eddy current-induced spin dephasing degrades the measurement accuracy.

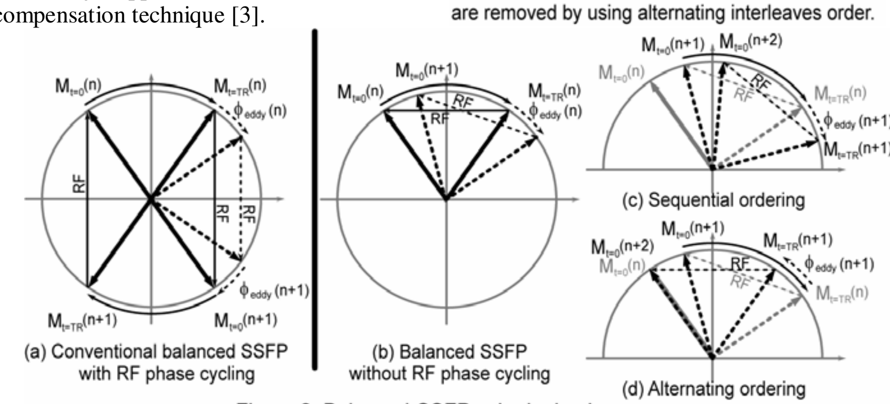

Figure 2. Balanced-SSFP spin dephasing

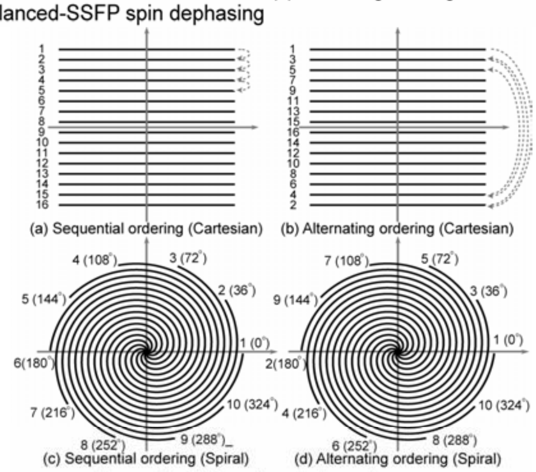

Figure 3. Different ordering schemes

Results

The resulting image from the alternating ordering scheme shows reduced imaging artifacts (Fig. 1b). The alternating ordering also provides significantly reduced eddy current-induced spin dephasing in the FID phase measurement (Fig. 4).

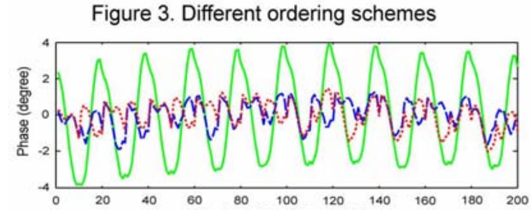

Figure 4. FID phase change due to the eddy current-induced spin dephasing. (Ninterleaves = 20, Nslice = 10). Green (solid): Sequential ordering, blue (dashed) : Alternating in spiral and sequential in Kz encoding. Red (dotted): Alternating ordering in both.

Discussion and Conclusion

A new interleaves (phase encodes) ordering method for non-phase-cycled balanced SSFP is presented and tested for a 3D stack-of-spiral sequence. With this method, the eddy current induced artifacts were clearly reduced and the respiration was measured with less noise. The proposed method can also be used to cover concentric trajectories because after an alternating pair the next phase encode can start anyplace as long as it is paired with its alternating phase encode one. Hence it can provide a similar phase encodes ordering flexibility suggested by [1].

References

[1] Bieri O. MRM 54:129-137 (2005) [2] Miller KL. MRM 50:675-683 (2003) [3] Lee J. ISMRM Miami. p.100 (2005)