Dual Acquisition Phase Difference SSFP for Improved Fat Suppression

C. J. Moran[1], and W. F. Block[2,3]

[1]Medical Physics, University of Wisconsin, Madsion, Wisconsin, United States, [2]Biomedical Engineering, University of Wisconsin, Madison, Wisconsin, United States, [3]Radiology, University of Wisconsin, Madison, Wisconsin, United States

INTRODUCTION: The high signal and rapid imaging inherently possible with balanced SSFP have motivated numerous solutions for suppressing its bright lipid signal. Linear combination SSFP (LCSSFP) separates fat and water by exploiting the relative difference in phase each species experiences in two passes with different RF phase cycling [1]. While effectively creating a π phase shift between the two passes should eliminate the unwanted species, magnitude differences between the passes causes incomplete suppression throughout the stopband [2], as shown in Fig. 1a. We present a method to suppress fat signal based on the phase difference between the two passes and demonstrate its effectiveness in knee and breast acquisitions.

Hargreaves has presented two phase-sensitive SSFP methods, where the optimal TR is set to 1/(Δf) where Δf is the fat/water chemical shift (4.8 ms at 1.5T). The first method used one pass and produced fat and water voxels differing by π in phase [3]. The second method used two passes, similar to LCSSFP, and analyzed the phase of the sum (pass 1 + pass 2). However, due to other causes of phase such as coil sensitivity and B0 inhomogeneity, a block-wise regional correction had to estimate and remove background phase before fat/water separation [4]. We instead have noticed the clear phase information provided by the difference in phase between the first pass and the second pass rotated by 90 degrees, or ϕ_{diff} = angle (pass 1) – angle(i*pass2). As shown in Figure 1b, the phase across subsequent pass and stop bands is either 0 or π. The reconstruction algorithm, however, is greatly simplified because common modes of phase errors cancel in the phase difference.

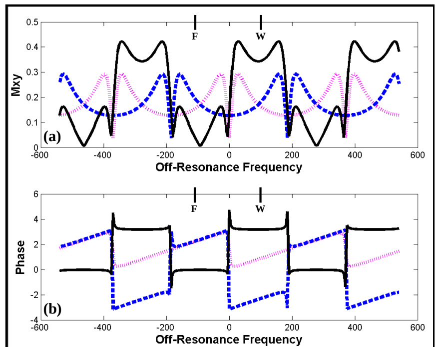

Figure 1. (a) Frequency response spectrum for LC-SSFP, 1st pass of data (dashed - blue), second pass of data (dotted - red), linear combination of 1st and 2nd pass (black), note suppression band is not absolute contributing to inconsistent fat suppression with LC-SSFP. (b) phase of 1st pass (dashed-blue), phase of i*2nd pass (dotted – red), phase of 1st pass – phase of i*2nd pass (black). Phase profile is flat and with π phase difference between water and fat regions of spectrum.

THEORY AND METHODS: The simple phase difference plotted in Fig. 1 holds for any echo time, not simply TR/2, and thus this method is applicable to numerous trajectories. We applied the method to the VIPR-SSFP [5] trajectory, which acquires two radial lines with echoes just after the RF pulse and prior to the next RF pulse. Considering the optimal TR of 2.4 ms for LCSSFP at 1.5T, VIPR-SSFP can acquire 2 passes with 2 radial lines each in effectively the same time that the single pass phase-sensitive method described earlier acquired one Cartesian phase encoding.

Motivated by the consistency of the phase differences between passes from our clinical studies, we generated a binary mask based on the phase difference and investigated its effect on fat suppression and overall image quality. To weigh the contribution of all coils based on SNR when calculating the phase difference, we computed the angle of the following sum

$$\sum_{c=0}^{\#coils-1} Z_{c,pass\ 1} \times (iZ_{c,pass\ 2})^*$$

where Z in the complex data from each pass. Phase differences of over 135° were classified as fat and set to zero. All datasets were acquired in 5 min using GE 1.5T Signa scanners (GE Healthcare, Milwaukee, WI). Breast scans used an 8 channel GE HD breast coil and had isotropic resolution of 0.63 mm using a 320 matrix and a 20 cm FOV with a 2.9 ms TR. Knee scans were acquired on a Twinspeed scanner and had isotropic resolution of 0.56 mm using a 320 matrix and a 20 cm FOV with a 2.5 ms TR.

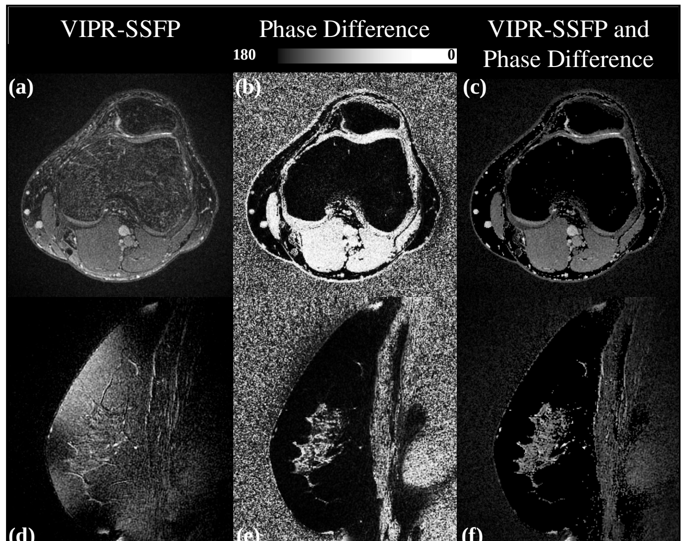

Figure 2. Axial reformats of knee (a) and breast (d) with VIPR-SSFP. Phase difference maps: phase of 1st pass – phase of i*2nd pass (b, e). VIPR-SSFP reformat with phase difference used for improved fat suppression. Note increase in contrast as well as the relatively clear representation of fat-water interfaces using the phase difference threshold (c, f).

RESULTS AND DISCUSSION: Inconsistent fat suppression was evident in both knee and breast images using linear combination VIPR-SSFP (Fig. 2, a & d). Phase difference maps showed clear separation of fat and water voxels (Figure2, b & e). The VIPR-SSFP image volumes with fat voxels suppressed based on the phase difference maps showed consistent fat suppression without severe compromise of morphologic detail at fat-water interfaces (Figure2, c & e). The drawback to using the phase difference is the loss of the ability to image partial voxels with water where fat dominates the phase calculation. This drawback is diminished due to the high isotropic resolution of VIPR-SSFP. While edges in the phase difference VIPR-SSFP images are, as expected, not as smooth as those in the original images, almost all edge detail is still well represented. Various techniques could be used to preserve the improved contrast due to the phase difference VIPR-SSFP while better representing partial voluming at the fat-water interfaces. One possible technique would involve refining the fat suppression based on the magnitude ratio between the first and second passes and possibly using Weighted Combination SSFP [2] when the ratio of passes is closer to 1. Opportunities also exist to make the phase calculation more robust to areas in which the signal from a single pass experiences a significant notch.

CONCLUSIONS: Using a phase difference map to threshold out fat voxels improves the suppression of fat tissue in VIPR-SSFP in the breast and knee. Despite the binary nature of this technique, the fat-water interfaces are still well represented due to the high isotropic resolution available with VIRP-SSFP. Future work will consist of refining the phase difference threshold through consideration of the magnitude ratio between the two acquisitions and investigation into use of the phase difference map to improve segmentation technique in the knee.

Acknowledgements Research supported by NIH 5T32 CA09206-26. We also gratefully acknowledge the support of GE Healthcare.

References 1. Vasanawala SS, *et al*., MRM, 43:82-90, 2000. 2. Cukur T, *et al*., Proc. 15th ISMRM, 1628, 2007. 3. Hargreaves BA, et al., MRM, 50:210-13 2003. 4. Hargreaves BA, et al., MRI, 24:113-122,2006. 5. Lu AM, *et al*., *MRM,* 53:692-699, 2005.