Fat Suppression with Weighted-Combination SSFP

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Introduction: Fully-refocused steady-state free precession (SSFP) sequences enable fast, high-resolution imaging with high signal-to-noise ratio (SNR). However the large fat signal in the acquired images is usually unwanted. One group of fat-suppression methods is characterized by the intent to generate a desired frequency response. This includes FEMR [1], LCSSFP [2], binomial excitation patterns [3], periodic flip angle variations [4,5] and fat suppressing ATR [6]. Although these methods create relatively broad stop-bands, the wedge shape of the stop-bands is unfavorable as it compromises the spectral fat suppression in the presence of moderate field inhomogeneities.

In this work, a new approach is proposed that achieves robust fat suppression by exploiting a combination of two SSFP images weighted by a power of their magnitude. As such, an almost perfect null is achieved for the frequencies in the stop-band while the pass-band is virtually unaffected. LCSSFP is demonstrated as a special case of the proposed method.

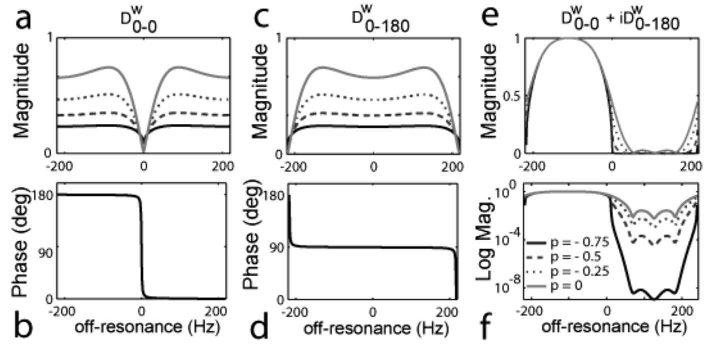

Figure 1. *Magnitude and phase profiles of the power-of-magnitude weighted SSFP datasets (**D^w**) with 0-0 (**a-b**) and 0-180 (**c-d**) phase cycling. The profiles of the resulting combined image in linear and logarithmic scales are shown in **e** and **f** respectively.*

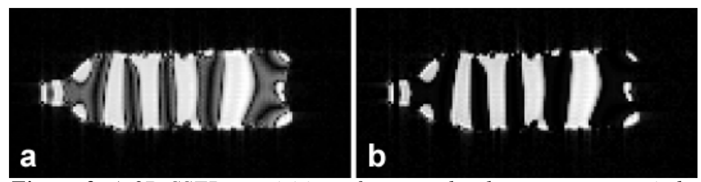

Figure 2. *A 3D SSFP acquisition of a water bottle was accompanied with a linear shim gradient in the readout (horizontal) direction to create bands. The LCSSFP (**a**) and weighted-combination SSFP (p=-0.5) (**b**) images are shown.*

Theory: The non-uniformity in the phase response of the SSFP data sets allows one to create a stop-band and a pass-band through linear combination of the data sets with the correct coefficients. Considering the (0-0) and (0-180) data sets, the phase difference between the two is 90° for one-half of the spectral period and -90° for the other half as displayed in Figure 1.(b,d). By adding a 90° phase to the (0-180) data set, the first half of frequencies become in-phase and the second half becomes out-of-phase. Therefore a summation of the two data sets is actually a subtraction for the second half of frequencies and a summation for the first half. This mechanism, which creates stop- and pass-bands [2], cannot create perfect stop-bands because at certain frequencies the two subtracted transverse magnetization amplitudes are not equal due to the presence of bands inherent in SSFP imaging.

If the amplitude difference between the subtracted points is decreased, then the stop-band will approach a perfect null. The range of amplitudes observed within a period of the spectrum can be reduced by weighting the SSFP data sets by a power **p** of their magnitude, if **p** is in the range (-1 0). Afterwards, the two data sets can be linearly combined to yield better suppression in the stop-band. The resultant image **Y**, can be expressed as a function of the phase-cycled SSFP images, $\mathbf{D_{0\text{-}0}}$ and $\mathbf{D_{0\text{-}180}}$: $|\mathbf{Y}| = |\, |\mathbf{D_{0\text{-}0}}|^{\mathbf{p}}\mathbf{D_{0\text{-}0}} + \mathbf{i}|\mathbf{D_{0\text{-}180}}|^{\mathbf{p}}\mathbf{D_{0\text{-}180}}\, |^{\mathbf{1/(1+p)}}$. The constant **p** determines the amount of distortion in the amplitude response and is directly related to the non-linearity of the combination. For **p** = 0, the combination is equivalent to LCSSFP.

Results and Discussion: The effects of the power-of-magnitude weighting on the magnetization profiles of the individual data sets and the resulting image are displayed in Fig. 1.(e,f). As **p** gets smaller, the stop-band suppression improves. However, the non-linearity of the combination also increases which may lead to some partial volume effects. For moderate values of **p** (≥ -0.5) and high-resolution imaging, this effect is negligible.

Figure 2 shows the LCSSFP and weighted-combination SSFP (**p** = -0.5) images of a water bottle with a linear shim gradient along the readout direction. The remnant signal in the stop-bands, clearly observable in the LCSSFP image (Fig. 2.a), appear dark in the weighted-combination SSFP image (Fig. 2.b). Slices from a 3DFT SSFP acquisition of a healthy volunteer's knee are shown in Fig. 3. The vessel visualization through maximum-intensity-projection is dramatically improved with weighted-combination SSFP due to superior fat suppression. The stop-band suppression is improved without compromising the SNR efficiency of the pass-band.

Figure 3. *3DFT - SSFP images of a knee TR/TE=2.7/1.12 ms, 1 mm isotropic, α=30°, 192x128x128 encoding, ±125 kHz bandwidth. Coronal and sagittal slices for LCSSFP (**a,b**) and weighted-combination SSFP (p=-0.5) (**d,e**). The corresponding MIPs in the R-L direction are **c** and **f**.*

References:
1. Vasanawala S, *et al.* MRM 42:876-83, 1999.
2. Vasanawala S, *et al.* MRM 43:82-90, 2000.
3. Hardy C, *et al.* Proc. 10th ISMRM, p.473, 2002.
4. Overall W, *et al.* MRM 50:550-59, 2003.
5. Absil J, *et al.* MRM 55:343-51, 2006.
6. Leupold J, *et al.* MRM 55:557-65, 2006.