An XS-Guided Solution for bSSFP Banding Artifact Correction with Reduced Scan Time

Michael Nicholas Hoff[1], and Qing-San Xiang[1,2]

[1]*Physics, University of British Columbia, Vancouver, British Columbia, Canada,* [2]*Radiology, University of British Columbia, Vancouver, British Columbia, Canada*

Introduction Balanced Steady State Free Precession (bSSFP) MRI suffers from signal modulation due to interpulse phase accumulation θ caused by off-resonance phenomena. bSSFP refocuses ample magnetization, but general signal modulation prevails, with dark bands arising if off-resonance frequencies exceed ±1/(2TR). Banding can be avoided by shortening TR and using powerful gradients, but SAR, TR limitations, and field inhomogeneity challenge these circumventions. Typically, band reduction is implemented through a combination of variably phase cycled images which have spatially shifted bands [1,2].

Previously we showed that it is possible to solve for the θ-independent bSSFP magnetization using four phase cycled images [3,4]. The need for scan time parsimony and the inherent redundancy indicated by two unique signal demodulation solutions [4] inspire the search for more efficient methods. Here we exploit the knowledge that the demodulated solution must lie somewhere between corresponding complex pixel values of two images relatively phase cycled by Δθ = 180°. A linear weighted solution is generated by analytically minimizing the regional differential energy (RDE) from a downsampled cross-point solution (XS, [3]), and is denoted the XS-Guided Solution (XGS).

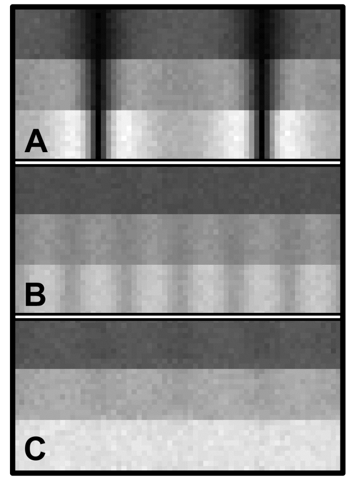

Fig.1: Simulated images. A. Δθ = 180° original image. B. 3pt complex sum. C. Weighted solution guided by 25% XS k-space coverage.

Methods Four simulated and four MR phantom images employed α = 40°, TE/TR = 2.1/4.2ms, and Δθ = 0°, 90°, 180°, and 270° respectively. Simulated images had θ = -2π → 2π varied horizontally, T1/T2 = 420/50, 240/70, and 2400/1400 stacked vertically (top to bottom), and added Gaussian noise (Fig.1A). 60x3mm slices of 3D TrueFISP (bSSFP) phantom data were acquired using a 1.5T Siemens Avanto scanner imaging a water bottle holding a Zimmer™ (Warsaw, IN) Co-Cr-Mo alloy hip prosthesis to provide off-resonance (Fig.2A).

For simulated and phantom data, all four phase cycled datasets were truncated in k-space to retain only the central phase encodes, low-pass filtered with a Hamming window, zero padded, inverse Fourier transformed, and computed as in [3] to yield a low resolution XS. An expression was formulated to compute pixel weighting between two full Δθ = 0° & 180° images by minimizing the RDE of the weighted solution relative to the low resolution XS guide. This formula was employed for all pixels, where each pixel's weight was calculuting using all local pixels with similar XS phase. Variable amounts of XS downsampling were tested, and the total relative error σ from a gold standard M_g (known simulated values or the full XS for phantom data) was computed with Eq.1. Δθ = 0°/180° (2pt), Δθ = 0°/120°/240° (3pt), and Δθ = 0°/90°/180°/270° (4pt) complex sum (CS) solutions were generated for comparison.

$$\sigma_i = 1000\frac{\sqrt{\sum_{x,y}\left[M_i(x,y) - M_g(x,y)\right]^2}}{\sum_{x,y} M_g\,(x,y)} \qquad (1)$$

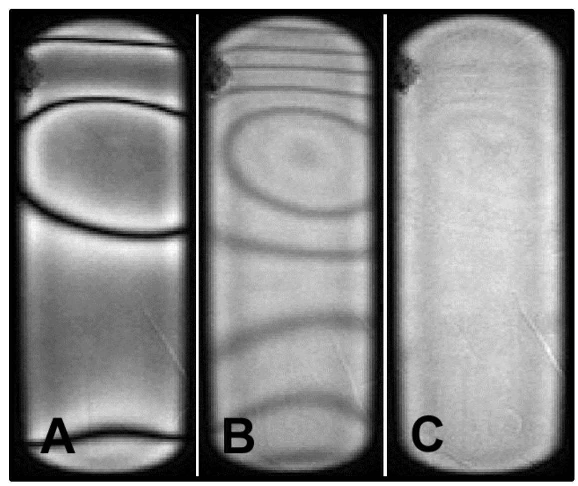

Fig.2: MR phantom images. A: Δθ = 180° original image. B: 3pt Complex sum. C: Weighted solution guided by 25% XS k-space coverage.

Results Fig.1 and 2 depict one full Δθ = 180° bSSFP image, the 3pt CS and the XGS using 25% XS k-space coverage for simulated and phantom data respectively. The XGS significantly diminishes signal modulation and bands. Fig.3 plots the error σ of the XGS vs. the XS k-space coverage for simulated data (left) and phantom data (right). The 2pt, 3pt, and 4pt CS σ values are plotted at comparable XGS scan times; since the XGS consists of two full scans plus two low resolution scans, 0% coverage ≈ two scans, 50% coverage ≈ three scans, and 100% coverage ≈ four scans. Both plots show that only 25% of k-space is needed for the XS to guide the XGS to minimal deviation from the gold standard relative to any CS method.

Discussion A guided solution to bSSFP demodulation is formulated and compared with the complex sum. While the XS can fully demodulate bSSFP signal, it is revealed that the XGS achieves substantial demodulation using a fraction of the data. Plots of σ vs. XS k-space coverage show that the XGS is most efficient when ~25% of k-space data is retained for the XS guide. This is temporally equivalent to acquiring 2.5 images, indicating that the XGS offers an excellent opportunity for accelerated bSSFP signal demodulation with band correction.

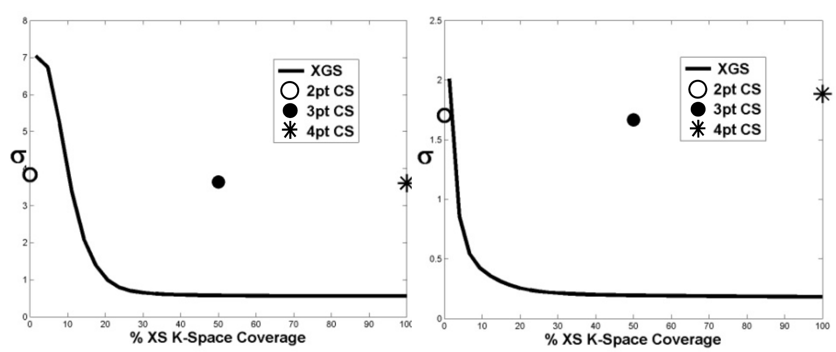

Fig.3: Guided solution (XGS) error curves for varied XS k-space coverage. Complex sum (CS) values which correspond to equal scan time requirements are shown for comparison. Simulated data is on the left and phantom data is on the right.

References

[1] Zur *et al*., MRM, 16:444-459, 1990.
[2] Bangerter *et al.*, MRM, 51:1038-1047, 2004.
[3] Xiang & Hoff, Proc. ISMRM, 18:74, 2010.
[4] Hoff & Xiang, Proc. ISMRM, 19: 2824, 2011.