Partially Dephased SSFP for Elimination of Dark Bands

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Introduction:

Balanced SSFP imaging sequences provide high signal-to-noise, rapid imaging, and diagnostically useful contrast, but their clinical utility is limited primarily by the dark-band artifacts that occur due to resonance variations, particularly at high fields or in areas of high susceptibility variations [1]. We show that by applying an unbalanced gradient over each sequence repetition and using a special reconstruction, images with balanced SSFP characteristics but without dark bands can be achieved. We refer to the new method as partially-dephased SSFP (PD-SSFP), based on previous reports for other applications [2,3].

Methods and Results:

A standard 3D balanced SSFP pulse sequence was used with the readout dephaser/rephaser gradients reduced for net dephasing over TR of one cycle per pixel in the readout direction. This positions the balanced SSFP signal response over imaged pixels as shown in Fig. 1a. The pixel signal becomes the average SSFP signal across the pixel, similar to slice-dispersed SSFP [4], with severe signal loss at certain resonant offsets (Fig. 1b) since successive SSFP pass-bands alternate sign [5]. Rather than using multiple acquisitions, a simple "shifted-pixel reconstruction" zero-pads k-space by a factor of 10 in the readout direction to allow reconstruction of sub-pixels between desired pixels such that at least one sub-pixel is centered on the pass-band (Fig. 1c). For each group of 10 pixels, the sub-pixel with highest signal was retained. (This does not gain resolution, but simply repositions pixels as in Fig. 1c.) A re-interpolation could correct the resulting sub-pixel shifts, but was not yet used.

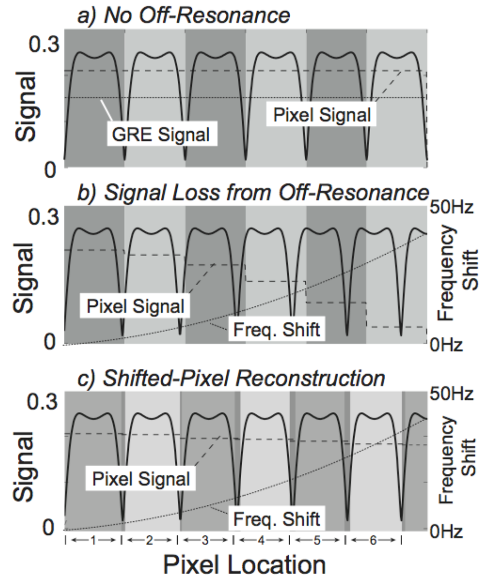

Figure 1: *An unbalanced gradient averages a single SSFP pass-band over each pixel (shaded regions) giving a higher signal than GRE, without signal nulls (a). Because signals in successive pass-bands have opposite sign, frequency offsets cause severe loss of the pixel signal (b), but by centering the reconstructed pixels on the pass-bands, this loss is avoided (c).*

We demonstrated this technique in a phantom with a square grid, using a 3T GE Excite scanner, TR=7ms, TE=3.5ms, and a 45 degree flip angle, and with background gradient shims in both readout and phase directions to create a significant frequency variation. We compared a gradient-spoiled (GRE) sequence with the same parameters to balanced SSFP and PD-SSFP. Results, shown in Fig. 2, are consistent with Fig. 1; PD-SSFP produces a higher signal than GRE, but without the dark bands of balanced SSFP. Next, we scanned 3 volunteers at 3T (after obtaining informed consent) with balanced SSFP and PD-SSFP using TR=2TE=6.0ms, a 256x256 matrix over 16cm FOV, and 32 sections each 2mm thick, with the readout along the S/I direction. Again, PD-SSFP eliminates dark band artifacts as shown in Fig. 3, with slight resolution loss.

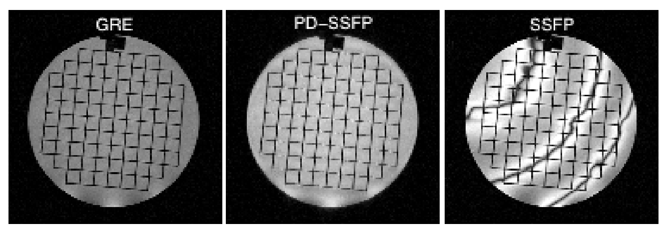

Figure 2: *Comparison of gradient-spoiled, partially-dephased SSFP and balanced SSFP images in the presence of a large field variation produced by background shim gradients. PD-SSFP gives a higher signal than GRE, but without the dark bands seen in balanced SSFP.*

Discussion:

PD-SSFP is a simple technique to remove the significant signal variations in balanced SSFP. The technique places a high-frequency modulation in the image, splitting the k-space signal into two islands toward the edges. Overlap of islands can result in resolution loss, though this can be compensated at small cost by using a higher matrix size in the readout direction, or by slightly reducing the net dephasing. The reconstruction described above is a simple peak-detection; more in-depth reconstruction techniques including re-interpolation or pixel selection using a field map should also mitigate some resolution loss. PD-SSFP is different from many gradient-spoiled techniques [6], in that imaging is midway between spoiler gradients resulting in a different spin ensemble, and thus different contrast.

Partial-dephasing can be in applied any direction, though the readout direction is preferred because it has the highest resolution, and PD-SSFP actually allows a small reduction in TR for a given readout by reducing gradient areas. Unlike the slice-dephasing technique [3], PD-SSFP requires only a single acquisition. Effects of subject motion as well as application of fat-suppression techniques will require additional experiments. Overall, PD-SSFP offers a promising trade-off between gradient spoiled sequences (GRE, FAST, GRASS, FISP etc.) and balanced SSFP (True-FISP, FIESTA, Balanced FFE) with the high signal and contrast characteristics of balanced SSFP, but without dark band artifacts,

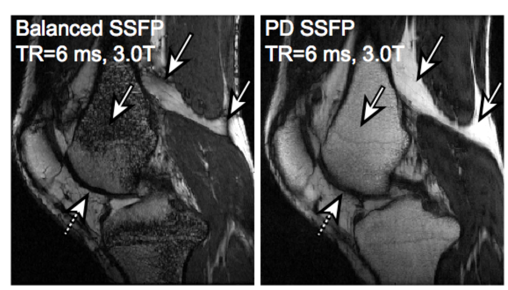

Figure 3: *Sample balanced and PD-SSFP knee images at 3T using TR=6 ms show elimination of shading and dark bands (solid arrows) at a cost of slight blurring (dotted arrows).*

References: [1] Oppelt A, Electromedica 54:15–18, 1986. [2] Epstein FH, et al. 9th ISMRM, p. 1786, 2001. [3] Baltes C, 12th ISMRM, p. 692, 2004. [4] Wachowicz K, Fallone BG, 15th ISMRM p. 1646, 2007. [5] Scheffler K and Hennig J, Magn Reson Med 49(2):395-397, 2003. [6] van der Meulen P, et al. Magn Reson Imaging 6:355-368, 1988.