DC Artifact Correction for Arbitrary Phase-Cycling Sequence

Paul Kyu Han[1], Jong Chul Ye[1], HyunWook Park[2], and Sung-Hong Park[1]

[1]*Bio and Brain Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Daejeon, Korea,* [2]*Electrical Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Daejeon, Korea*

Introduction:

Image reconstruction of MRI data with Fourier transform often results in a bright spot or a line parallel to the frequency-encoded direction in the center of the image. This artifact, known as direct current (DC) artifact, is due to receiver baseline offsets and free induction decay (FID) or non-phase-encoded stimulated echo signals [1]. Removal of this DC artifact can be done by taking into account the hardware information or by acquiring the data using specific techniques. These methods include (i) cropping a few lines at the edge of field of view (FOV) after Fourier transform of data acquired with phase cycling radio frequency (RF) excitation pulses with alternating opposite phases, (ii) removal of FID artifacts with phase-cycling of excitation pulses but not the refocusing pulses, and (iii) RF chopping where the phases of the RF excitation pulses for each signal average is offset by 180° when even number excitations (NEX) is employed in the data acquisition [2]. Although these techniques are usually sufficient for DC artifact removal in most of the cases, these methods fail and cannot be directly applied when phase information is incorporated into the pulse sequences, such as in the case of phase-cycled balanced steady state free precession (bSSFP) [3], or for cases with odd number of NEX. Here, we propose a novel technique that allows for the correction of DC artifact for any phase-cycled pulse sequence. The proposed method includes receiver phase unification and its reversal before and after the application of a usual DC artifact removal technique in the specifically phase-cycled pulse sequence. DC artifact removal for phase-cycled balanced steady-state free precession (bSSFP) is shown for demonstration of the concept by incorporating the phase-cycling angle information of the RF excitation pulse and the phase encoding acquisition order. Results show complete removal of the DC artifact for phase cycling angles of 0°, 90°, 180°, 270° in the phase-cycled bSSFP sequence, and provides useful insight for the application of DC artifact removal in other phase-cycled pulse sequences.

Material and Methods : All experiments were performed on a 3T whole body scanner (ISOL Technology, South Korea) operated with a Varian spectrometer. A circularly polarized head coil was used for both transmission and reception. All *in vivo* studies were performed with approval from local institutional review board.

Phase-cycled bSSFP images were acquired on a resolution phantom. Imaging parameters were TR/TE=6.6/3.3 ms, flip angle = 40°, matrix size = 128 × 128, FOV = 240 × 240 mm^2, thickness = 5 mm, gap = 1 mm, scan direction = axial, PE order = linear, and scan time per dataset = ~4 sec. To test the effect of the proposed technique in a phase-cycled pulse sequence, we varied the phase-cycling angle (0°, 90°, 180°, 270°) in bSSFP pulse sequence.

Acquired datasets were further processed with receiver phase unification (Fig.1, a), DC artifact removal (Fig.1, b) and reversal of the phase unification (Fig. 1, c) steps. Receiver phase unification was performed by multiplying each K-space line with a phase-shift with opposite polarity ($e^{-j\phi}$) associated with the phase shift ($e^{j\phi}$) from the phase cycling. DC artifact was removed with an ordinary background subtraction technique. Four 5 by 5 size matrices were constructed in each corner of the image and an average value was calculated and then subtracted from the whole k-space image. The corresponding phase shift ($e^{j\phi}$) from the phase cycling was multiplied back into each line of the resulting K-space. The corrected K-space datasets were Fourier transformed to compose images.

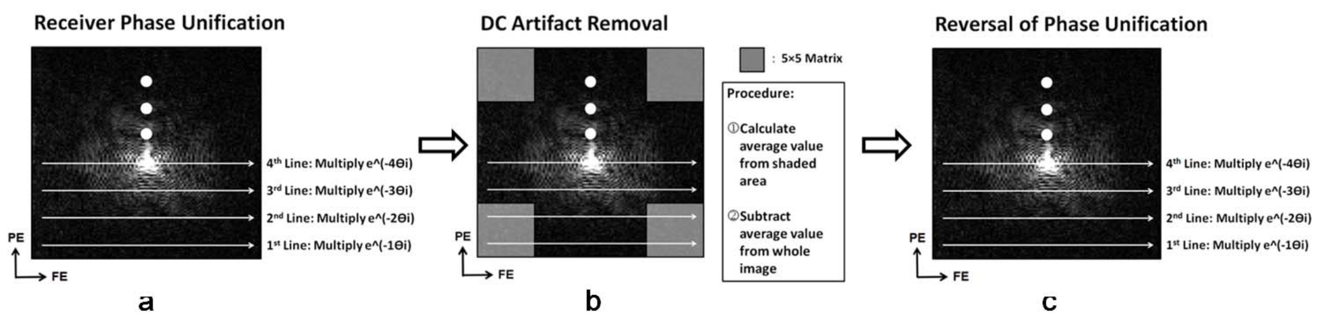

FIG. 1. Flow chart of the proposed DC artifact removal technique for phase-cycled bSSFP pulse sequence. The process consists of a receiver phase unification (**a**), DC artifact removal (**b**), and reversal of the phase unification (**c**) steps.

Results and Discussion : Figure 2 shows the experimental results for the phantom. DC artifact shift for each phase-cycling angle is shown in each set of image, attributed to receiver phase shifts of each K-space lines associated with the phase cycling angles. With the new DC correction technique, the DC artifact is removed in the phase-cycled bSSFP sequences. Note the locations of the banding artifacts also shift as a function of phase cycling angle.

All experimental results show that the DC artifact was completely removed using the proposed technique, regardless of the phase-cycling angle. This indicates that the technique can be applied to any phase-cycled pulse sequences, as long as the phase shift for each K-space line is known.

In summary, DC artifact removal with the proposed technique allows for the removal of DC artifact for phase-cycled bSSFP sequences. The proposed technique potentially works for other phase-cycled pulse sequences or for cases where the phase of the RF excitation pulse is varied within a specific pulse sequence.

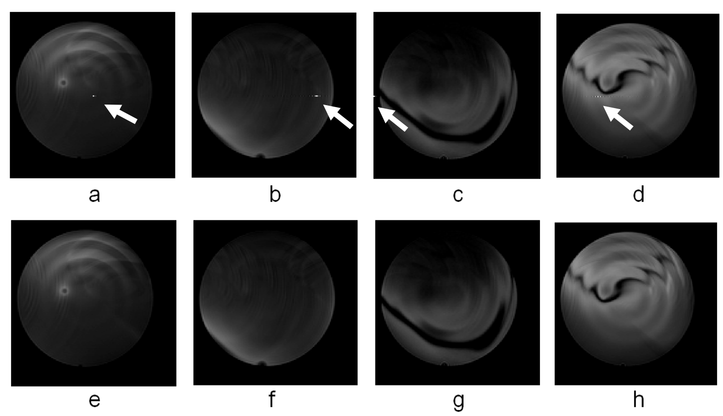

FIG. 2. Image results of the phantom experiment without **(a,b,c,d)** and with **(e,f,g,h)** the proposed DC artifact removal technique in phase-cycled bSSFPs. Image results for phase cycling angles of 0° **(a, e)**, 90° **(b, f)**, 180° **(c, g)** and 270° **(d, h)** are shown. Arrows represent the locations of the DC artifacts.

References :

1. Henkelman and Bronskill, Magn. Reson. Med. 1987; 2:1-126
2. Bernstein et al, In: Handbook of MRI pulse sequences. Burlington, Mass: Elsevier Academic Press, 2004.
3. Park et al, NeuroImage 2011;58:168-176.