# Slice-wise Nyquist Ghost Correction for Slice-Accelerated EPI

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**Target Audience:** Researchers interested in using slice-accelerated imaging with echo planar imaging.

**Purpose:** Simultaneous multi-slice (multiband) echo planar imaging (EPI)[1,2] including blip-controlled aliasing (blipped-CAIPIRINHA)[2] has been recently demonstrated to be extremely effective. However, there is a significant amount of time taken by the EPI reference (ghosting calibration) and parallel imaging calibration scans, both of which are performed individually for each slice. Also, due to the slice aliasing of multiband data, it is difficult to correct for ghosting until after the parallel imaging step, prompting a dual-GRAPPA kernel approach to mitigate residual ghosting[2]. **This work demonstrates a fast and reference-free method to perform slice-wise Nyquist ghost correction on multiband EPI data with or without blipped-CAIPIRINHA**.

**Theory:** The method proposed here is similar to the image entropy minimization technique proposed by Nordell[4]; however it is extended to correct for slice-aliased scans. The algorithm can be easily parallelized and further acceleration is gained by automatically grouping coil elements for processing based on their z-position. The detailed steps of the algorithm are as follows:

1) Using the GRAPPA calibration scan, perform a brute force then a simplex search for a minimum image entropy solution for each slice and coil group to find the EPI ghost correction parameters for the calibration scan.
2) Slice-alias the de-ghosted calibration image to match the multiband acquisition. This generates images (from the calibration scan) that match the ideal (de-ghosted) multiband images.
3) De-ghost the multiband image based on the parameters found in step 1, and then fine-tune the de-ghosting using a normalized mutual information (NMI) metric for each multiband slice and coil group compared to the same slice-overlaid calibration image and coil group (generated in step 2). Even though the slices are overlaid, the coil elements and NMI metric serve to implicitly provide slice separation in the multiband scan and therefore allow for slice-wise de-ghosting before slice separation.

**Methods:** Acquisitions: EPI diffusion and fMRI scans were acquired on a GE 3T scanner (MR750, GE Healthcare, Waukesha, WI, USA) and a 32-channel head coil (Nova Medical, Wilmington, MA, USA). fMRI: Slice/in-plane accelerations=2/3, matrix of 84x84, 16 slices, slice thickness 6mm, a FOV/z-FOV= 24/12.6cm. DTI: Slice/in-plane accelerations=2/2, blipped-CAIPIRINHA FOV/2 shift, matrix of 128x128, 32 slices, slice thickness 5mm, a FOV/z-FOV= 26/16cm. Matching EPI GRAPPA calibration scans without simultaneously acquired slices was used for ghost correction in both cases. Nyquist ghost correction: The EPI ghost correction described in the theory section was implemented in MATLAB (Mathworks, Natick, MA, USA). Reconstruction: Slice-GRAPPA[2] and SENSE-GRAPPA[5] were used for the DTI and fMRI respectively.

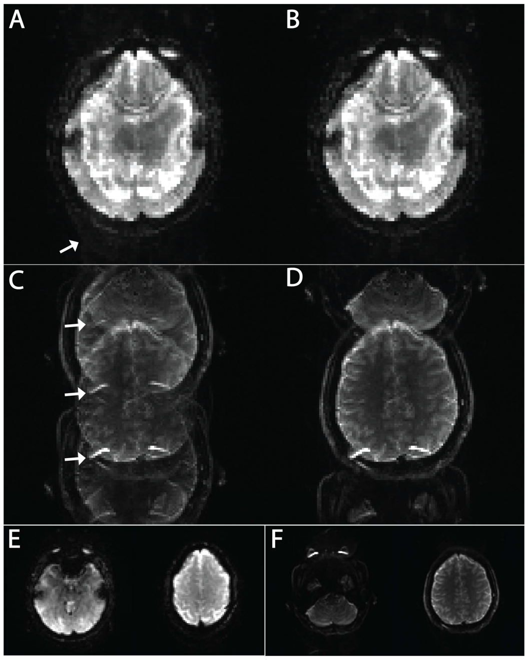

Figure 1: A) Overlaid slices from a non-CAIPIRINHA multi-echo fMRI acquisition before ghost correction. Note that only very slight ghosting is present before correction. B) The same slices from A, but after ghost correction. C) Overlaid slices from the b=0 image from a blipped-CAIPIRINHA DTI acquisition before ghost correction. Note that the eyes are clearly visible in 3 places before ghost correction. D) The same slices from C, but after ghost correction. E) Slices from A after slice separation. F) Slices from C after slice separation.

**Results and Discussion:** The advantages of the Nyquist ghost correction algorithm described here and shown in Figure 1 over previously used methods are twofold. The primary advantage is that no time is taken for a separate reference scan (which takes at least an extra 30s); the EPI ghost correction parameters are calculated from the GRAPPA calibration scan. The secondary advantage is that by calculating separate EPI ghost correction parameters for each slice and coil element, slice-wise ghost correction can be done on the multiband scan before performing any parallel imaging separation, which allows for standard parallel imaging processing to be used while maintaining robust performance. While this method necessitates additional processing time, finding the ghost correction parameters is only necessary for a single volume per scan, and can be quickly applied to the remaining volumes. The time associated with parameter finding was about 60 and 90 seconds for the fMRI and diffusion scans respectively, which is less than 25% of the total reconstruction time in both cases.

**Conclusion:** The method described here allows for a reduction of scan time by removing the need for a reference scan, and provides robust, simple, and reliable EPI ghost correction without significantly increasing the reconstruction time. Furthermore, it provides pre-slice separation ghost correction, which enables standard parallel imaging reconstructions.

**References:** 1. Setsompop et al. NeuroImage 2012; 63(1), 569-80. 2. Ugurbil et al. NeuroImage 2013; 80:80-104. 3. Setsompop et al. MRM 2012; 67(5), 1210-24. 4. Nordell A et al. ISMRM 2007:1833. 5. Moeller, et al. MRM 2010; 63(5), 1144-53.

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