# Combination of Partial *k*-Space and Direct Virtual Coil Parallel Imaging

P. J. Beatty[1], A. Madhuranthakam[2], S. Chang[3], E. Bayram[3], and J. H. Brittain[4]

[1]Global Applied Science Laboratory, GE Healthcare, Thornhill, Ontario, Canada, [2]Global Applied Science Laboratory, GE Healthcare, Boston, Massachusetts, United States, [3]GE Healthcare, Madison, Wisconsin, United States, [4]Global Applied Science Laboratory, GE Healthcare, Madison, Wisconsin, United States

**Introduction** Direct Virtual Coil (DVC) parallel imaging [1] is a data-driven technique that delivers similar image quality to coil-by-coil approaches [2,3], such as GRAPPA, while reducing memory and compute requirements by over 10X for high channel count coil arrays. Partial k-space acquisitions are routinely combined with parallel imaging to reduce scan time or achieve a smaller echo time. In this work, we describe how Direct Virtual Coil (DVC) parallel imaging reconstruction can be combined with both zero filling and homodyne partial k-space reconstructions. Compared to coil-by-coil reconstructions, the proposed approach greatly reduces the computation required for partial k-space processing, since the partial k-space processing only needs to be performed for one virtual coil instead of for each coil. In vivo partial k-space accelerated datasets are acquired and used to compare image quality between coil-by-coil reconstructions and DVC. Results indicate that DVC can achieve similar image quality to coil-by-coil reconstructions of partial k-space accelerated data.

**Theory** For coil-by-coil methods, partial k-space processing occurs before channel combination (Fig. 1). Conversely, for the DVC method, homodyne processing occurs *after* channel combination. Channel combination in the DVC method can be understood as a convolution of source channel data with channel combination kernels. Shown in Fig. 2, there are different choices for where this convolution is terminated at the border between acquired phase-encode lines and the unacquired part of k-space.

**Methods** Healthy normal subjects were imaged with a single-shot fast-spin-echo (SSFSE) pulse sequence on a 1.5T scanner (HDx, GE Healthcare, Waukesha, WI) using a 32-channel torso array. Data was internally calibrated with outer parallel imaging acceleration factors of 2-4. A coil-by-coil + sum-of-squares reconstruction was performed with both zero filling and homodyne processing and compared to six potential DVC reconstructions: zero filling and homodyne for each of the 3 border cases illustrated in Fig. 2. The combination kernel used had width 5 in the ky direction.

**Results** Figure 3 displays results of the study for an acquisition with 18 calibration lines and an outer acceleration factor of three. As expected for a partial k-space factor of 0.54, the zero filling results are blurry. Although the differences are small, brightened difference images reveal subtle ringing that occurs in the zero filling case when the convolution is halted prematurely (Fig. 2(a),(b)). In this case, allowing the convolution to fill in as many lines as possible led to a reconstruction that was the most similar to the coil-by-coil reconstruction (case (c) – red box). When homodyne processing was employed, the reconstruction that was closest to the coil-by-coil reconstruction was when DVC synthesized the same phase encode lines as were acquired on the source channels (case (b) – red box). This is not surprising as case (b) keeps the homodyne filters identical between methods.

**Discussion** Our results indicate that for partial k-space acquisitions, the DVC method achieves comparable image quality to coil-by-coil reconstructions. By combining data from all acquisition channels early in the reconstruction pipeline, DVC not only reduces the computation and memory requirements for parallel imaging processing, it also reduces the computation required for partial k-space processing, since the processing need only be performed on the virtual coil data and not for every acquisition channel. Reversing the order of the homodyne and channel combination steps in the reconstruction pipeline did have a detectable effect on image quality. For the DVC method, how the border is chosen for the virtual coil data can have an impact on the final image quality. As described in our results, how the border should be chosen is different depending on whether zero filling or homodyne processing is used for the partial k-space reconstruction.

**References** [1] Beatty et al., ISMRM 2008, p8.
[2] McKenzie et al., 2001, MRM 46:619-23.
[3] Griswold et al. 2002, MRM 47:1202-10.

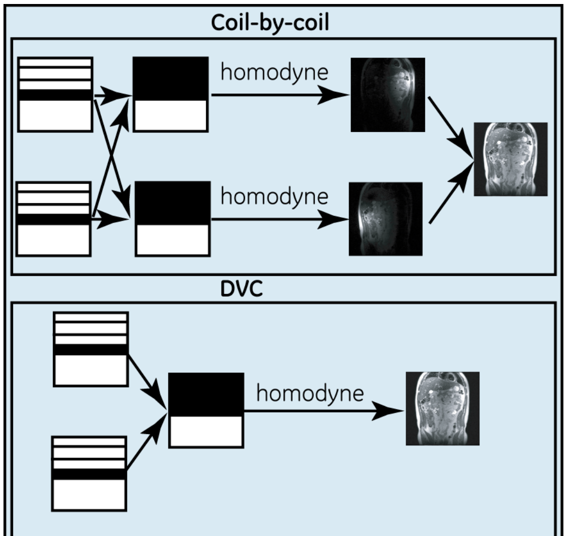


**Figure 1** For coil-by-coil reconstructions, homodyne processing is performed separately for each channel, before channel combination. For direct virtual coil (DVC), channel combination happens before homodyne processing; homodyne processing is performed only on the virtual coil data.

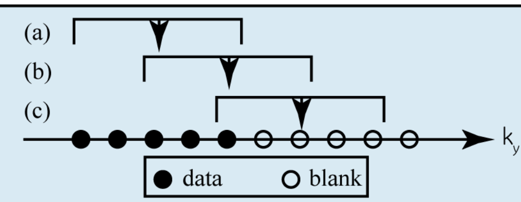


**Figure 2** DVC synthesizes data for a virtual coil. For partial k-space acquisitions, how should the synthesis boundary be chosen? For a width 5 channel combination kernel, three possibilities are examined, (a), (b), (c) as shown.

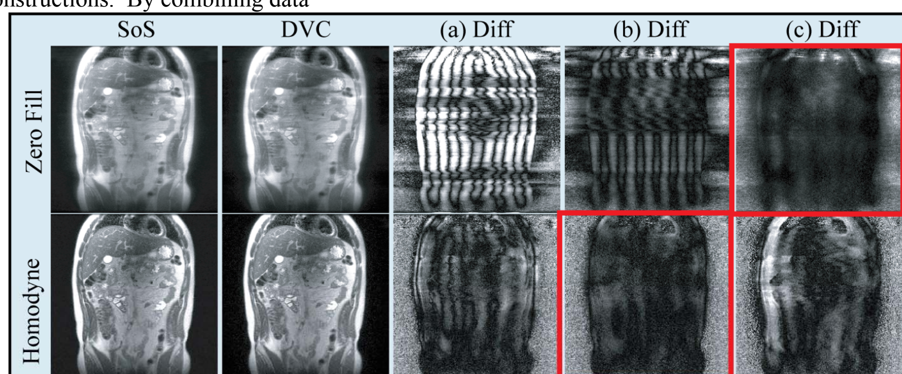


**Figure 3** Reconstruction results for 0.54 partial k-space SSFSE acquisition. A coil-by-coil reconstruction with sum-of-squares channel combination was performed with both homodyne and zero filling (left). Six DVC reconstructions were performed: synthesis border at locations (a), (b) and (c) with both zero filling and homodyne. Red boxes highlight the ideal border choice for zero filling (c) and homodyne (b) reconstructions. DVC reconstruction results are shown for the ideal border choices (second column).