COMbining Phased array data using Offsets from a Short Echo-time Reference scan (COMPOSER)

Simon Daniel Robinson[1], Wolfgang Bogner[1], Barbara Dymerska[1], Pedro Cardoso[1], Günther Grabner[1], Xeni Deligianni[2], Oliver Bieri[2], and Siegfried Trattnig[1]
[1]High Field MR Centre, Department of Biomedical Imaging and Image-guided Therapy, Medical University of Vienna, Vienna, Vienna, Austria, [2]Division of Radiological Physics, Department of Radiology, University of Basel Hospital, Basel, Switzerland

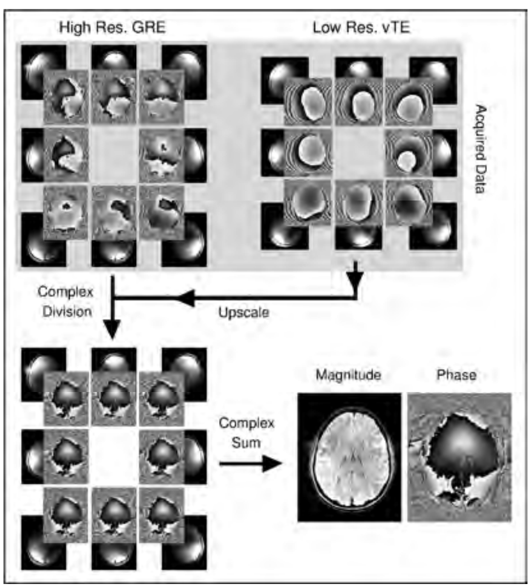
Target Audience: Scientists interested in improving signal combination from receive array and PTx coils, especially for UHF phase imaging.

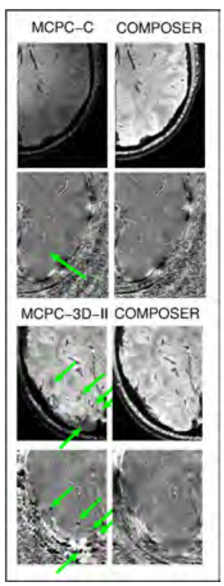
Introduction: Phase information is used in neuroimaging in phase-contrast angiography, Susceptibility-Weighted Imaging (SWI) [1], susceptibility mapping [2] and to depict iron accumulation in neurodegenerative disorders. Phase imaging benefits from strong susceptibility effects at very high field and the high SNR afforded by multi-channel coils. Combining the phase information from coil arrays is not trivial, however. The phase in each coil comprises both local field effects (the source of interesting contrast) and an offset which needs to be removed in order to be able to combine complex coil data. This has been done by referencing individual coil sensitivities to that of a volume coil [3], but alternative approaches are required for PTx coils and some ultra-high field arrays for which no reference coil is available. One possibility is to calculate the offsets from a multi-echo acquisition (MCPC-3D) [4], although this requires phase data to be unwrapped, which is time consuming and prone to error. We present a new method which uses a reference scan acquired at an echo time which is sufficiently short that approximates to the complex coil sensitivity (the phase part of which is the offset). We call this approach COMbining Phased array data using Offsets from a Short Echo-time Reference, or COMPOSER.

Materials and Methods: Measurements of 3 healthy subjects were made with a 7 Tesla MR whole body Siemens Magnetom scanner and a 32 channel Nova Medical head coil. The high resolution gradient-echo scan to be reconstructed was a 3D flow-compensated acquisition with $0.3\times0.3\times1.2$ mm^3 resolution, T_E/TR = 15/28 ms, TA=12 mins. The sensitivity maps for COMPOSER were acquired with a 3D variable T_E (vTE) sequence which uses asymmetric readouts and the shortest echo time possible for each readout [5] ($2\times2\times4$ mm^3 resolution, T_E/TR = 0.8/5 ms, TA = 11 s). A 2D dual-echo gradient-echo scan was acquired with (T_{E1},T_{E2})/TR = (4.6, 9.3)/606 ms, GRAPPA 4, TA = 27 s for one of the comparison methods, MCPC-3D.

Analysis: Image reconstruction with COMPOSER is illustrated in Fig. 1. It consists only of coregistration of the vTE sensitivity maps to the high resolution scan, complex division, summation over channels and extraction of the magnitude and phase of the summed complex signal. Magnitude and phase images from COMPOSER reconstructions were compared with those generated with i) image-based phase matching by subtracting a constant, 'MCPC-C', following ref [6], and ii) the MCPC-3D-II method according to [4], the latter using the unwrapping methods PHUN [7], PRELUDE in 2D and 3D [8] and Cusack's method [9] to unwrap separate channel data. Combined phase images from all approaches were unwrapped using a Laplacian method [10]. The quality of phase matching in each voxel was assessed via the metric 'Q', the ratio of the magnitude of the combined result to the sum of the individual channel magnitudes (which approaches 100% for perfect matching).

Results: Magnitude and Q values were low for MCPC-C, reflecting poor phase matching, and phase images correspondingly noisy (Fig. 2, top left quadrant at green arrow and Fig. 3). Magnitude and Q values were higher with MCPC-3D, although errors in unwrapping single-channel phase values led to localised artefacts in both phase and magnitude images (Fig. 2, bottom left quadrant at arrows and Fig. 3). Phase matching was near perfect with COMPOSER (the single-channel phase images in Fig. 1, bottom left, appear identical after complex division); no artefacts were present in images (Fig. 2) and Q values were close to 100% (Fig. 3, note log scale). The median value of Q was 20.7% with no correction, 47.6% with MCPC-C, 89.1-95.2% for MCPC-3D (depending on unwrapping method) and 98.8% for COMPOSER.





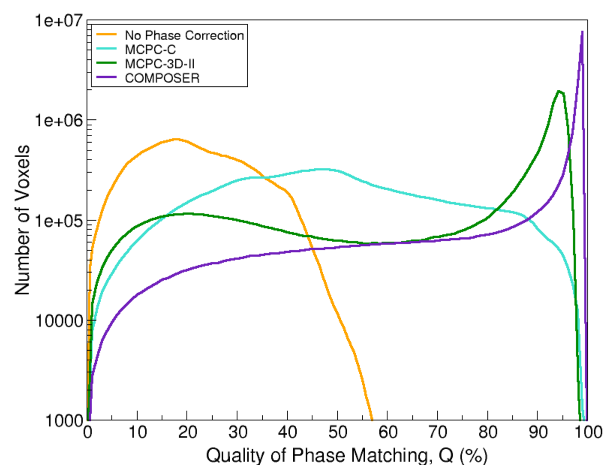


Fig. 1 (left): Steps in COMPOSER, illustrated for 8 elements of a 32-channel head array
Fig. 2 (centre): The quality of combined magnitude and phase images generated with the COMPOSER method compared to MCPC-C phase matching [6] (top half) and MCPC-3D-II [4].
Fig. 3 (right): A histogram of the quality of phase matching Q (see main text) in all in-brain voxels in a single subject.

Discussion and conclusion: COMPOSER is a fast, robust method for the phase-sensitive combination of data from coil arrays. It requires no reference coil, making it feasible for use all coil arrays, including e.g. PTx coils and surface arrays. COMPOSER needs no phase unwrapping and provides phase matching which is superior to that with the rival approaches tested [4, 6].

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