Auto-Calibrating the Z-shim for Slice Specific Recovery of Susceptibility Losses

K. A. Heberlein[1], X. Hu[1]

[1]Dept. of Biomedical Engineering, Emory/Georgia Tech, Atlanta, GA, United States

INTRODUCTION: Signal loss due to susceptibility artifacts precludes the study of many areas of the human brain using BOLD fMRI with T_2^*-weighted imaging. Often the region of signal loss can be regained through the use of compensation gradients applied in the slice direction. Susceptibility induced field variations may be approximated by a small linear gradient in the slice selection direction. This small gradient causes spin dephasing that is proportional to the slice thickness and the echo time, leading to signal loss. A compensation gradient, or z-shim [1], can be applied to recover the majority of this signal loss. Z-shim has been incorporated into several pulse sequences [2-5], including ZSAGA [2], which is used in this work. Manual calibration of the z-shim can be time consuming and operator dependent, especially when multiple slices are used. This paper describes a method for fully-automated slice specific z-shimming applicable to whole brain, BOLD fMRI studies.

METHODS: All experiments and sequence development were performed on a Siemens 3T Trio system equipped with gradients capable of 40mT/m in 200µs. The calibration scheme relied on field maps acquired in the same planes as T_2^*-weighted EPI slices. An interleaved spin echo EPI sequence was developed, first to acquire spin echo images in one repetition, while asymmetric spin echo images are acquired in a second repetition with a 2 msec offset. The EPI acquisition parameters for the spin-echo sequence were the same as those of the T_2^*-weighted EPI. They are a 220 mm FOV, 64 matrix, a bandwidth of 2442Hz/pixel, and 20 5-mm axial slices. The field map for each slice was calculated based on the phase difference of two spin-echo images. The field maps were intensity thresholded to remove background pixels and processed with a 7 point median filter to remove spurious pixel values from the phase subtraction. To estimate the gradient along the slice direction in each slice, a three point linear fit was applied pixel by pixel to field maps of three consecutive slices centered on the slice under consideration. Finally, the automated algorithm identifies, in each slice, the region with the highest gradient by including all pixels with a gradient above 50% of the maximum value in the slice. The mean value of the gradient in the region is stored for each slice in a control file that is read by the subsequent T_2^*-weighted EPI acquisition. For our experimental setup, the control program of our ZSAGA pulse sequence [2] sets the slice specific compensation gradients by matching the area of the gradient to the product of the field gradient and the user requested echo time.

RESULTS AND DISCUSSION: Results in 4 slices near the region of a strong susceptibility change of the brain are presented for a normal human volunteer in Fig. 1. Both the field maps and the field gradient maps are displayed in the top two rows. As can be seen from the measured gradient field, a strong variation is apparent across individual slices. This result reinforces the need for slice specific calibration of the z-shim. The images in the subsequent rows show the results of the auto-calibrated z-shimming applied in the ZSAGA acquisition. A strong correspondence is shown between the strength of the field distortion, the resulting signal loss, and subsequent signal recovery. Even in slices with subtle artifacts, which would be problematic for manual adjustment, robust z-shim gradient estimations are made. With this method, operator independent calibration of the z-shim for whole brain studies is feasible in a fraction of the time needed for manual adjustments.

REFERENCES: 1. Frahm J, et al. MRM 6:4 1998. **2.** Heberlein K, et al. MRM 51:1, 2004. **3.** Glover GH, MRM 42:2, 1999. **4.** Song AW, MRM 46:2,2001 **5.** Yang QX, et al, MRM 39:3 1998

Figure 1. Experimental results from the slices that exhibited the most field inhomogeneity in a normal volunteer. The z-shims were estimated as the mean value of the distortion region and were stored for use by the subsequent ZSAGA image acquisition shown in the bottom three rows.