Rapid Volume Shimming with Gradient Reversed EPI

Kevin Koch[1], Eric Printz[1], and Dan Xu[1]
[1]*GE Healthcare, Milwaukee, Wisconsin, United States*

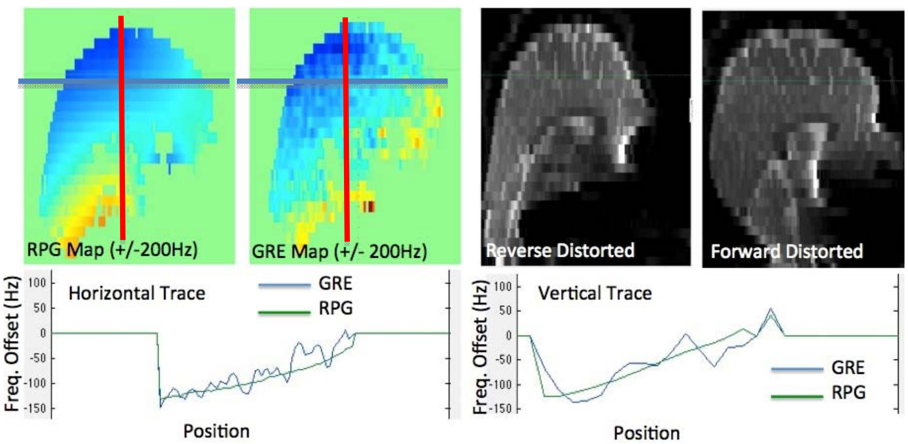
Introduction: Target audience. Developers and researchers interested in spatially accurate rapid B0 field map estimates. Static field shimming is an important aspect of many clinical imaging protocols. Clinical shimming typically only consists of

Introduction: Static field shimming is an important aspect of many clinical imaging protocols. Clinical shimming typically only consists of trimming or offsetting the linear X, Y, and Z imaging gradients. Projection, columnar, or tri-planar dual-TE gradient echo acquisitions are often used to estimate linear field trends across a volume of interest--with a paramount focus in minimizing pre-scan time. This being the case, linear terms are usually optimized using field maps with limited spatial coverage. Higher-order terms require full volume field maps, which require tens of seconds (if not minutes) to acquire. Here, we present a method by which multi-slice, high-SNR, volumetric field-maps can be acquired in a matter of seconds and used for true volumetric shim optimization.

Theory: It has previously been shown that two echo-planar images (EPI) acquired with reversed phase-encoding blip gradient polarities can be used to construct shift maps that map the two distorted images to one another [1,2]. In particular, the method presented by Holland et al [1] allows for robust estimation of shift maps without prior knowledge of the underlying B0 distribution. Briefly, the algorithm follows a schedule of successive blurring steps, each of which is followed by the solution of a cost-function comparing the two source images. The cost-function minimization problem is linearized (Newton's method), and the resulting linear system is solved using established iterative methods. Each solution of the linearized cost function is added to the cumulative shifts computed at previous blurring steps.

An important property of this algorithm in the present context is that it allows for specialized handling of massively distorted source images (such as when the background shim field is not pre-set). Such cases can be accommodated by increasing the starting blurring kernel width, and in the case of low-order shim optimization, the kernel reduction step size can also be adjusted to facilitate faster map computation.

Figure 1: *Comparison of gradient-echo and RPG field maps. Top row shows maps (masked by ROI determined from distorted source RPG images). Traces of maps shown.*



Methods: As a benchmark comparison, a conventional gradient echo field map (acquired in the axial plane) was acquired on the brain at 3T using an 8 channel receive array. Two images (128x128 over 28 slices) were acquired at echo times of 3.80 ms and 4.15 ms, which required a total acquisition time of 1.1 minutes. Phase differentials were calculated between the two echo-time images, and then the phase difference was converted into a frequency offset map using the two image's echo time separation. Maps were calculated individually for each channel, and then averaged to form a composite map.

Reversed encoding Polarity Gradient (RPG) shift maps were estimated from two single-shot spin-echo EPI acquisitions. The total acquisition time for both images was 3 seconds. The images were acquired over the exact geometry as the gradient-echo field map acquisition. The RPG shift map calculation algorithm, as presented in [1], was implemented in C++ and run on a MacBook Pro (2.3 GHz, 8GB RAM). A large starting blurring kernel of 35 pixels was utilized in order to stabilize the shift map in the presence of large shifts expected when shims are not utilized or are mis-set. The algorithm then followed a blurring schedule, whereby the kernel was reduced by 2 pixels for each successive iteration. The final shift map was scaled by the phase-encoded pixel bandwidth of the RPG acquisitions. Shims were set to zero for both the gradient echo EPI and RPG acquisitions.

Shim ROIs were automatically determined using the RPG source images. To find the best-behaved regions of field distribution, voxels over a given intensity threshold in both the forward and reverse polarity images were identified as ROI coordinates. Linear (X,Y,Z) were then calculated over this ROI on both the gradient-echo and RPG field maps using a least-squares linear solver in Matlab.

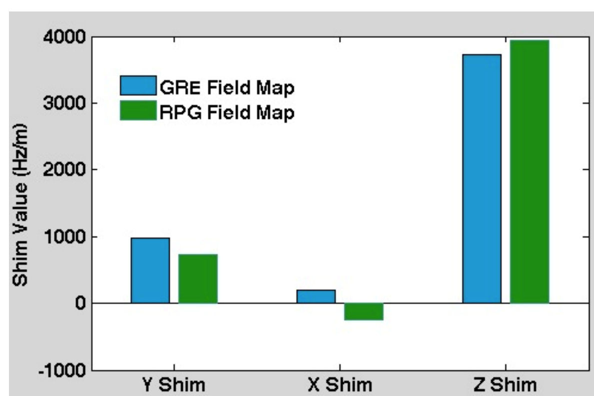


Figure 2: *Shim coefficients as calculated by the gradient echo (GRE) and RPG field maps.*

Results and Discussion: Figure 1 presents a comparison of linear shimming using gradient echo and RPG field maps. The top row depicts maps and indicated traces, along with the source distorted RPG images. The maps are shown over the automatically determined ROIs used for shim optimization. Traces show field trends in both maps. The field map determined from the dual-echo gradient echo images is noticeably noisier than that determined from the RPG algorithm. This is due to the use of limited phase-evolution in determining the frequency offset. Increasing the acquisition time of the gradient-echo map (more averages, more echoes) can improve the resulting field map noise. The RPG algorithm produces a very smooth field map, which is the result of using post-coil-combined magnitude source images, as well as a smoothing regularization term in its cost-function. The spatial line-plots for the two maps show clear linear trends, and very close agreement with one another. Figure 3 shows the linear terms calculated from each of the maps. The differences between the shim coefficients have minimal impact on post-shimmed field homogeneity.

In conclusion, we have demonstrated a mechanism that allows for rapid volumetric optimization of linear shim terms on high-SNR spatially accurate field map estimates. It is anticipated that the presented methods could also be used for estimation of higher-order shim currents. Future work will investigate such extended applications.

[1] Holland et al, Neuroimage 50, 2010 [2] Andersson et al, Neuroimage, 20, 2003