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# Open-Source, Multi-Vendor B0 Shimming Protocol

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## Synopsis

**Keywords:** Shims, Shims

**Motivation:** Harmonize the B0 shimming prescan step for multi-site fMRI and MRI studies.

**Goal(s):** Create an open-source, multi-vendor B0 shimming protocol with equivalent performance to vendors' shimming methods.

**Approach:** We calibrate shim coil effects to a spherical harmonic basis and use regularized field maps to solve for shim coefficients to improve B0 homogeneity. We compared whole-brain field maps before and after applying our shim tool to both GE and Siemens built-in shimming protocols. We also compare the performance of our tool for the brainstem region.

**Results:** Our protocol can be run on both vendors and performs similarly to vendor protocols.

**Impact:** The proposed open-source B0 shimming protocol runs on multiple vendors' scanners, increasing the harmonization of experimental workflows for multisite MRI and fMRI studies.

## Introduction

B0 shimming is the first step in the MRI workflow and can improve image quality by reducing B0 inhomogeneity which causes distortions in EPI images and T2* signal loss. While vendor shimming methods are effective at improving field homogeneity, shim calculation methods can differ between vendors and are opaque to users. In addition, the exact voxels actually used in the shim calculation routine may be unknown to the user and beyond their control. This can make it difficult to obtain consistent B0 shim settings across sites in multi-site studies. The open-source Shimming Toolbox (https://shimming-toolbox.org/) addresses this problem by integrating vendor B0 mapping sequences with a dedicated off-line shim calculation tool[1]. Our approach is similar to [1] but in addition we (1) use a Pulseq vendor-agnostic B0 mapping sequence to guarantee identical field mapping protocol settings across vendor platforms and sites, (2) regularize field maps to make calculated shim settings more robust to potential outliers, (3) exploit the scanner's data streaming capabilities to automate field map raw data transfer from the scanner to the external laptop used for shim calculation, and (4) exploit the scanner's terminal command line interface to automatically apply calculated shim settings, to reduce potential human error.

## Methods

<u>Workflow:</u>
Figure 1 illustrates the overall workflow. A Pulseq[2,3] B0 mapping sequence is used to obtain a field map of the subject. Data is streamed directly to an external workstation for reconstruction and calculation of the required shim values. Raw multi-coil data is sent using the Raw Data Server on GE scanners and the NIH Data Catcher software on Siemens scanners.
Our default ROI selection method masks the whole brain using the Brain Extraction Tool in FSL[4], and applies a magnitude threshold mask. Other ROIs can be made using, e.g., the Shimming Toolbox plugin for FSLeyes[1], or using graphical selection tools in Julia as we have done here.
We create regularized field maps using the MRIFieldmaps.jl toolbox for Julia[5]. An initial field map is calculated using the traditional phase difference approach that we then unwrap using the ROMEO.jl toolbox[6]. The regularized field map algorithm takes the complex multi coil data, echo times, ROI mask, and the unwrapped initial field map to create a regularized field map.
Our toolbox requires a shim calibration procedure to relate changes in scanner shim settings to resulting B0 field changes. The calibration procedure only has to be done once on each scanner and consists of collecting a series of field maps with different shim settings in a stationary phantom.The resulting calibration matrix A is used to calculate shim changes in subsequent scan sessions (Fig. 1).
<u>Data Acquisition:</u>
We evaluated the workflow on Siemens and GE 3T scanners. Whole brain field maps were acquired with a Pulseq 3D GRE sequence with TE = 2.22 ms and 4.45 ms ensuring that water and fat are in phase. We compared the resulting field map homogeneity to the linear "Autoshim" and "High Order Shim" Tool (HOS) on GE and "Tune Up" and "GRE_Brain" shimming methods on Siemens. In addition, on GE we selected the brainstem as a smaller shimming ROI where the field maps were compared similarly.

## Results

Figure 2 shows that field maps using the proposed shim tool have similar homogeneity (root mean squared (RMS) difference) to the vendors' second-order shimming methods and improved homogeneity over the linear methods. Figure 3 shows similar results for the localized shim over the brainstem where the proposed method improves the ROI homogeneity significantly compared to the vendor's whole-brain linear Autoshim protocol.

## Discussion

The proposed workflow runs on both Siemens and GE scanners and offers a comparable performance to the built-in shimming methods. Our B0 shimming protocol uses a Pulseq B0 sequence to guarantee identical field map acquisition settings, regularized field mapping for robustness to outliers (which may be particularly useful for small ROIs), and raw data streaming and script (terminal) based shimming to reduce latency and reliance on manual interventions.
Certain experimental settings may have influenced the comparisons presented here. First, the exact ROI geometry when using vendor methods for both whole brain and local shimming is unknown, which may have influenced the direct comparison. Second, the subject scanned on Siemens in Figure 1 had a dental implant which could have affected the performance of the shimming protocols.

## Conclusion

The proposed shimming protocol allows for shimming across multiple vendors and sites while providing a transparent workflow and shim region selection.

## Acknowledgements

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## Figures

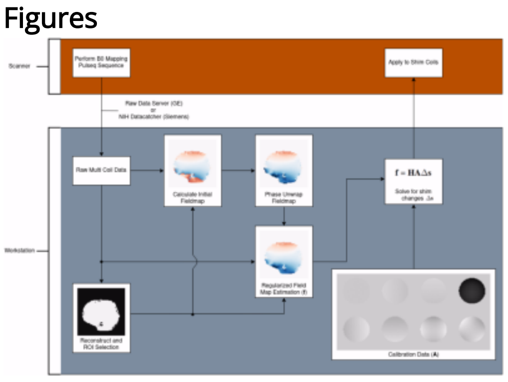


Figure 1: Outline of the data movement through the shimming protocol. Raw multi-coil data of the subject is streamed to an external computer, where the shim region is selected and an initial field map is unwrapped. These values are used to calculate a regularized field map **f**. Calibration data for each shim channel is collected at a previous date and used to calculate a calibration matrix **A**. The calibration matrix and regularized field map are fit to a spherical harmonic basis H to calculate the recommended shim changes **-Δs**.

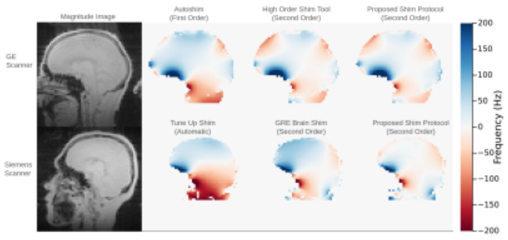


Figure 2: Whole-brain B0 shimming using the proposed toolbox on a GE 3T and a Siemens 3T scanner. A different subject was scanned on each scanner. Column two shows GE's linear Autoshim and Siemens' Tune Up shim. The second column shows the vendors' methods for second order shimming using GE's HOS tool and Siemens' GRE-Brain shim. The last column shows our second order shim on both GE and Siemens. We calculated shim settings to minimize RMS on each scanner independently.

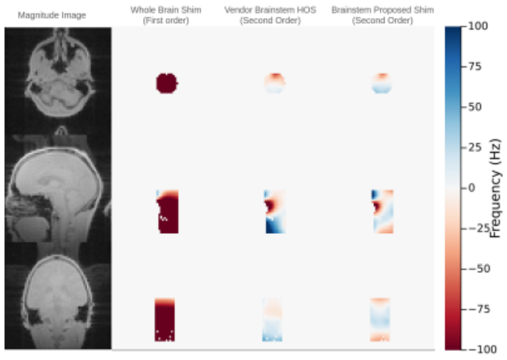


Figure 3: Localized shimming around the brainstem on a GE 3T scanner. The second column shows the field map in the brainstem from GE's Autoshim which sets linear shims based on three orthogonal 2D acquisitions covering the whole brain, resulting in large B0 offsets in the brainstem. The right two columns show field maps after applying the vendor's HOS tool and after applying our method. ROIs for our tool and the HOS tool were somewhat different which could account for the RMS difference.

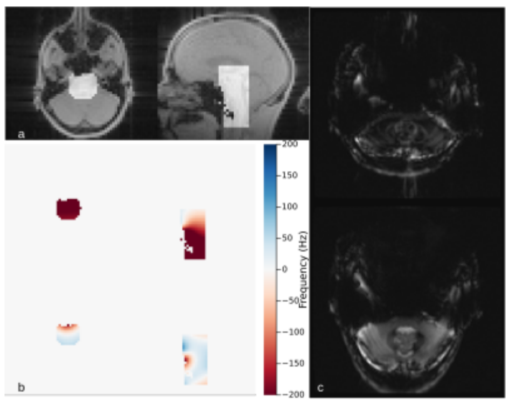


Figure 4: Impact of localized shimming on EPI images around the brainstem. (a) 3D GRE image with the local shim region covering the brainstem highlighted. (b) B0 map before (top) and after (bottom) localized 2nd order shimming using the proposed shimming toolbox. (c) 2D axial EPI images before (top) and after (bottom) localized shimming (matrix size 128x128, slice thickness 4mm). Brainstem and cerebellum regions around the ROI have improved signal and fewer distortions after applying the proposed shim.

| Subject | Vendor | ROI | Vendor Autoshim (Homogeneity RMS in Hz) | Vendor Second Order Shim (Homogeneity RMS in Hz) | Proposed Second Order Shim (Homogeneity RMS in Hz) |
|---|---|---|---|---|---|
| 1 | GE | Whole Brain | 59.05 | 46.54 | 46.39 |
| 2 | GE | Whole Brain | 130.90 | na | 32.39 |
| 3 | GE | Brainstem | 156.86 | 49.71 | 26.66 |
| 4 | Siemens | Whole Brain | 113.12 | 60.36 | 44.31 |
| 5 | Siemens | Whole Brain | 92.91 | na | 34.89 |
| 6 | Siemens | Whole Brain | 91.85 | na | 33.91 |

Figure 5: B0 root mean squared (RMS) residuals in 6 subjects comparing vendor shimming techniques to the proposed second order shim. RMS values are calculated as the average difference from the mean across all voxels in the ROI. Data from vendor second-order shims was not acquired (na) for some subjects. Field maps from Subjects 1 and 4 are in Figure 1, and Subject 3's field map is shown in Figure 3.

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