# Sample-Specific Passive Shimming Using Optimization Algorithm

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## Introduction

In high field MR systems, $B_0$ field inhomogeneity is a critical issue. Even after applying linear and 2nd-order harmonic shimming to in vivo volumes, significant residual $B_0$ inhomogeneity remains. Key portions of the remnant fields are due to higher-order inhomogeneity fields that exist near the vicinity of air cavity regions. It has been shown that additional passive shims can further enhance the homogeneity in these cases [1]. The position of the passive shims have been typically placed at fixed regions or manually adjusted. While these methods provide increased homogeneity, further improvements are possible if the positions can be optimized for individual samples. Here, we present a sample-specific passive shimming method. In this method, a shimming structure which is capable of adjusting the position of the passive shims is built. The optimal shim positions are computed using a convex optimization algorithm. The investigation is aimed to establish the utility of passive shimming on the human brain through automatic shim optimization. Compared to previous in-vivo passive shim approaches [1,2], the proposed passive shim system avoids trial and error approach to find the best shimming position. The results demonstrate that passive shims are very sensitive to location and sample specific passive shimming can be a robust method for improving $B_0$ homogeneity in vivo.

## Methods and Theory

Constructing a shim structure: A shimming structure was built, which can place the passive shims to the desired positions. The structure was first designed using CAD and built using Acetal material. The assembly was designed so that the structure securely tightens on to the head coil. A rail-like feature is added where the arms containing the passive shims are placed. These arms can then be freely moved to the desired position. Figure 1 shows the details of the constructed shim structure.

Passive shim material modeling: The fields of magnetized spheres can be expressed in terms of simple functions [3]. In the case of spheres centered at the origin, the expression follows as

$$\Delta B_z = 2\Delta\chi / 3B_0 \quad \text{in side the sphere and}$$

$$\Delta B_z = \Delta\chi / 3B_0 a^3 (2z^2 - x^2 - y^2)/(x^2 + y^2 + z^2)^{5/2} \quad \text{outside the sphere.}$$

We used a paramagnetic material (niobium, $\chi$= +237 ppm) and a diamagnetic material (bismuth, $\chi$= -164 ppm) for the passive shims.

Optimization search algorithm: A line search strategy was used for implementation of the automatic optimization search algorithm using MATLAB. A field map of human brain using a GRE sequence is obtained in vivo and calculated. Using the material model equation, optimization routine is performed to generate the optimal position for shimming the material. The objective function to minimize is

$$\sum_{j=1}^{M} [T(r_j) - R(r_j)]^2, \quad R(r_j) = O(r_j) - F(r_j)$$

, where each $r_j$ is the spatial position within a target ROI, $j$ is the element position to find, $T(r_j)$ is target field, $O(r_j)$ is the field map of human brain, and $F(r_j)$ is material field. The passive shims are located to the position found by the optimization scheme.

Comparison study: The EPI sequence was used for evaluation of the subject specific passive shim routine. Images were compared using linear shims, 2nd order shimming, and passive shimming. Also, the sensitivity to optimal positioning was studied by comparing passive shims at fixed locations versus passive shims at the position calculated by the optimization routine. All experiments were performed on a Siemens 3T Trio scanner.

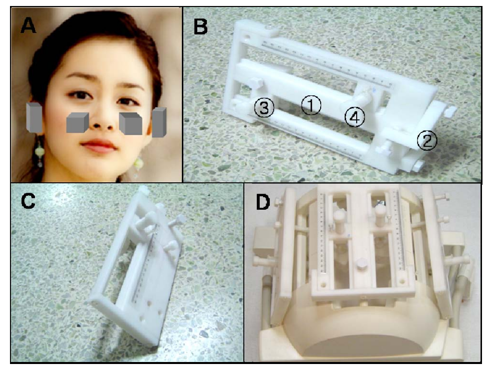


Figure 1: Shim assemblies. A) typical shim positions in head B) sinus structure ① body structure ② mounting structure ③④ shim controllers which can move up upward, downward or rotate up to 180° C) auditory structure D) head coil combined with the structures

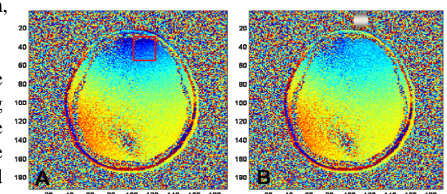


Figure 2: A) original field map B) corrected field map

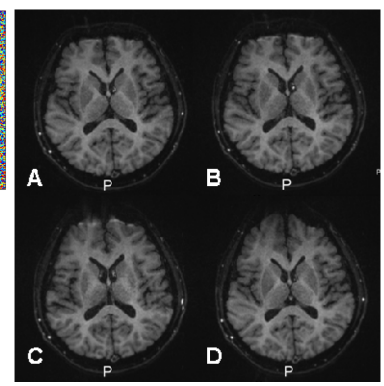


Figure 3: A) EPI + linear shimming B) A + high order shimming C) B + fixed position passive shimming D) B + optimized position passive shimming

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|---|---|
| Average mse improvement for fixed positioning | 2.80 ± 6.34 Hz |
| Average mse improvement for adjustable positioning | 8.79 ± 1.20 Hz |

Table 1: mse comparison between fixed and optimized positions

## Results

A field map before and after optimized passive shim placement is seen in Figure 2. We can select the desired ROI for one slice, multi slices or even volumes. The mean squared error (mse) of the original field map was 35.53 Hz and it was reduced to 26.32 Hz after shim placement using the optimized position for the region shown. Figure 3 demonstrates the improved correction using optimized passive shims. Optimized positioning as shown in D provides further improvement in the EPI image. Table 1 shows the average mse improvements between shims at fixed positions versus shims located at the optimized positions. Note the differences between fixed positioning versus adjustable positioning. The high deviation for fixed positioning implies that while fixed positioning can improve homogeneity in some cases, it can actually degrade the homogeneity as well. This shows that passive shimming is very sensitive to the location of the shims. Using adjustable positioning, the homogeneity is significantly improved while subject to subject variations can be reduced.

## Conclusion

We applied sample specific passive shimming with optimized positioning by building a shim assembly composed with adjustable substructures and by implementing a convex optimization which calculates the optimal positions. The ability to freely place the passive shims at the desired position gave significantly improved images using an EPI sequence, which is commonly used protocol for fMRI and DWI. It is believed that this method can play an important role in achieving field homogeneity in the clinical MR environment as well. Future work includes placing the materials precisely and reducing the optimization time.

## References

[1] K. M. Koch et al., JMR, 182 :66-74, 2006 [2] K. M. Koch et al., Proc. ISMRM, 15:982, 2007 [3] L. F. Schenck, Med. Phys. 23(6):815-850, 1996