# A novel localized passive shim technique for optimizing magnetic field of the human orbitofrontal cortex at high field

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**Introduction**: The orbitofrontal cortex (OFC) area plays a critical role in human brain functions. However, the great distinction in magnetic susceptibility between paranasal sinuses and the surrounding tissues of the nasal cavity leads to local susceptibility-induced field variations in the OFC that cause artifacts such as image distortion and signal loss. In addition to active and global passive shimming, localized passive shimming has been used to reduce field deviations over the OFC region for high field MRI.[1] For passive shimming, it is advantageous to position shim elements away from the subject and reduce discomfort.[2] In this work, we propose the use of magnetic material to generate the passive shim field and improve the field homogeneity within a group of subjects' brains, particularly in the OFC. The simulated residual field maps of each individual subject's brain show significant improvement in the field homogeneity and verify the accuracy of using our novel passive shim technique.

**Theory**: Spherical shim elements, which can be diamagnetic and/or para/ferromagnetic material, with radius $a$ and susceptibility $\chi_{i(\pm)}$ placed at the predefined position ($x_{oi}$, $y_{oi}$, $z_{oi}$) of a passive shim system in a main magnetic field gives rise to a magnetic induction out side the sphere at the position ($x$, $y$, z) as shown in Eq. (1)[3,4]

$$\Delta\vec{B}_{OUT}(x_{jkl}) = \sum_i \frac{a_i^3 \cdot \chi_{i(\pm)}}{3}\left[\frac{(2.(z-z_{0i})^2-(x-x_{0i})^2-(y-y_{0i})^2)}{((z-z_{0i})^2+(x-x_{0i})^2+(y-y_{0i})^2)^{(\frac{5}{2})}}\right]\cdot\hat{k} \qquad (1)$$

Here, $x$, $y$ and $z$ are Cartesian coordinates describing 3D space and $i$ represents the number of shim pieces. The simplified version of the Eq. (1) is given below.

$$\Delta\vec{B}_{OUT}(x_{jkl}) = \sum_i \beta.f(x_{ijk})\cdot\hat{k} \qquad (2)$$

Here, $f(x_{jkl})$ and $\beta_i$ are spatial dependent components and amplitude of the generated passive shim field, respectively. The amplitude, $\beta_i$, depends on the magnetic susceptibility and dimensions of each individual shim inserts. The least-squares optimal $\beta_i$ is given by

$$\beta_i = [f(x_{jkl})^T.f(x_{jkl})]^{-1}.f(x_{jkl})^T.\overline{\Delta H_Z}(x_{jkl}) \qquad (3)$$

Here, $\Delta H_Z(x_{ijk})$ is the measured inhomogeneous magnetic induction at position $x_{jkl}$ (The -1, T superscripts represent matrix inversion and transposition, respectively). The average amplitude is given by Eq. (4) below ($n$ is the number of subjects in the group).

$$\beta_{av,i} = \sum_{S=1}^{n}\beta_{S,i}/n \qquad (4)$$

**Methods**: A 3D gradient-echo pulse sequence with modifications to reduce eddy currents was used to calculate $B_0$ field map of four volunteers' brains by comparing the phase of two images acquired at two echo times (TE=5.25 and 7ms, TR=16ms, 10° flip, 256x256x256mm FOV, 128x64x64 matrix) on a 4T whole-body Varian INOVA system. Phase-difference reconstruction was used to generate the $B_0$ map with 3D phase unwrapping as necessary. The best mounting positions of the half cylindrical geometry (i.e. the basic passive shim geometry) were determined. The positions of the shim elements for each field component were evaluated with the adaptations for passive shim design. The measured, uncorrected field distribution of each subject was then projected onto Eq. (3) to obtain the desired amplitudes $\beta_i$ of each individual subject. Then the average amplitudes were computed using Eq.4 for correction of the inhomogeneity. With the positions and average $\beta_{avi}$ selected, the required susceptibilities $\chi_{i(\pm)}$ and dimensions were determined.

**Results**: Fig 1(A) shows the passive shim system with diamagnetic (green) and para/ferromagnetic (red) shim pieces for generating the average dipole passive shim field. Fig. 1(B) shows the field map following first and second order active shimming. The simulated residual field map after removal of the average dipole passive shim and optimal active shim field is shown in Fig. 1(C). These figures demonstrate that the presented technique can be used to improve the field homogeneity considerably over the entire brain particularly in the OFC.

**Discussion**: Even if the field homogeneity is improved within the subject's brain after introduction of the 3rd order shim system, the field inhomogeneity is not significantly reduced within the OFC (data not shown). The simulation results show that this method effectively improves the field homogeneity, particularly in the OFC for a group of subjects (n=4). The generated passive shim field may sometimes overly compensate the field in some regions within the brain of some individuals. However, the results showed that the system worked generally well for all subjects if optimal positions and shim materials were determined.

**Reference; [1]** Osterbauer et al., NeuroImage 29, 245-53 (2006).; [2] M. Jayatilake et al.,Proc. Intl. Soc. Mag. Reson. Med. 17 (2009); [3] F.Schenck et al., Med. Phys. 815 – 850 (1996); [4] J.L. Wilson et al., MRM 2002; 48:906-914.

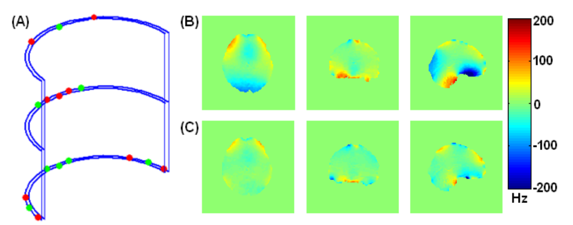


**Figure 1** Passive shim systems for shimming the human OFC at 4T. (B) Axial, coronal and sagittal slices of the active shimmed $B_0$ field of the subject's brain. (C) Simulated residual magnetic field for cylindrical placement of passive shim elements.