# Magnetic field shimming of a 2.0 T permanent magnet using a bi-planar single-channel shim coil

Daiki Tamada[1], Katsumi Kose[1], and Tomoyuki Haishi[2]
[1]Institute of Applied Physics, University of Tsukuba, Tsukuba, Ibaraki, Japan, [2]MRTechnology, Inc., Tsukuba, Ibaraki, Japan

## Introduction

There are two approaches to magnetic field shimming, passive and active shimming $B_0$ inhomogeneity $\Delta B_0$ is corrected using a number of shim coils which are respectively designed to generate a magnetic field corresponding to one of usually orthogonal functions such as spherical harmonics. However, such multi-coil shimming requires a number of power supplies and consumes installation space in the magnet bore or gap. To overcome these problems, we proposed a single-channel shim coil (SCSC) design method [1, 2]. This method is based on superposition of traditional second order shim coil elements proposed by W. Anderson [3]. However, this "conventional" SCSC cannot correct the higher order terms of $\Delta B_0$effectively. To achieve more homogeneous field, correction of higher order term inhomogeneities is indispensable. Recently, a shimming concept using a set of circular coils has been proposed. It can correct a complicated $\Delta B_0$ by driving coils individually [4]. In this study, we propose a "novel" SCSC design method using a circular current array to correct higher order inhomogeneities.

## Materials and Methods

Experiments were performed using a yokeless permanent magnet ($B_0$ = 2.0 T, gap width = 60 mm, weight = 1,600kg) [5]. The $\Delta B_0$ distribution was measured using a 3D lattice phantom consist of 11 acrylic discs (diameter=23.9 mm, length=62 mm). The 3D images of the phantom were measured using 3D SE sequence (matrix=$256 \times 128 \times 128$, voxel size = $(100\ \mu m)^3$ ) with positive and negative readout gradients. The spatial distribution of the magnetic field was calculated from the 3D images using a GUI program. The $\Delta B_0$ was fitted to a linear combination of spherical harmonics up to the fifth order.

In our method, the current density of the SCSC was designed using a superposition of a number of circular current placed on the $n \times m$ square lattice as shown in Fig. 1(a). Since the field $B_s$ generated by the SCSC was a linear combination of the field $B_{nm}$ generated by each circular current element, $B_s = \sum_{n,m} c_{nm} B_{nm}$, where $c_{nm}$ is the coefficients for the linear combination. These coefficients were determined using the non-linear least squares method to minimize $\sqrt{\frac{(B_s - \Delta B_0)^2}{V}}$, where V is volume for evaluation ( $(20\ \mathrm{mm})^3$ cubic area ). Then, the current density $J_s$ for the SCSC can be expressed as follows: $J_s = \sum_{n,m} c_{nm} J_{nm}$, where $J_{nm}$ is a current density of each coil element. To minimize local heating, the current density was convoluted with a Gaussian filter. The winding patterns were derived from $J_s$ using the stream function method. Finally, a winding pattern for the SCSC was obtained as contour lines of stream function.

## Results and Discussion

Figure 1(b) shows the upper and lower winding patterns designed for the 2.0 T permanent magnet. The design parameters are as follows: gap = 50 mm, current flowing plane = $140 \times 140$ mm, number of current loops = $5 \times 5$, diameter of the loops = 30 mm, wire diameter = 0.5 mm. Figure 1(c) shows peak-to-peak (PP) values of $\Delta B_0$ calculated for the "theoretical" conventional and novel current patterns and "experimental" current patterns for the novel design plotted against the shim coil current. This graph clearly shows that the PP value was improved by about 40% both theoretically and experimentally using the novel design comparing to the conventional design. Figures 1(d) and 1(e) show coefficients of fourth and fifth order terms of the magnetic field inhomogeneity calculated without SCSC and with conventional and novel SCSC. This graph clearly shows that the higher order terms were drastically reduced using the novel design. In this study, we have succeeded in decreasing the PP value of the $\Delta B_0$ by about 40% using the novel SCSC design. In conclusion, the novel SCSC design method is a simple and powerful technique for shimming $\Delta B_0$ including higher order terms.

## References

[1]D. Tamada et.al. Appl. Phys. Express 3, 066702 (2011) [2] D. Tamada et al. Proc. ISMRM, 2011, 1802 [3] W. A. Anderson et.al. Rev. Sci. Instrum 32, 241-250 (1961). [4] C. Juchem et.al. J. Mang. Reson 204, 281-289 (2010) [5] T.Haishi et.al. Proc. ISMRM, 2005, 869

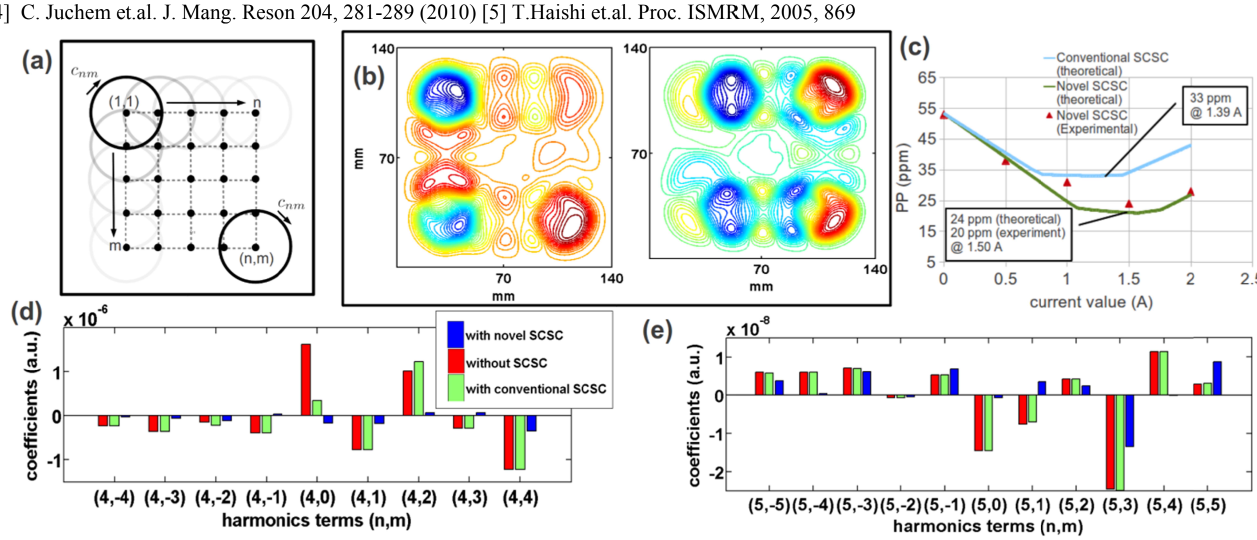


Fig. 1 (a) Diagram for the design method of the SCSC using circular current elements. (b) The winding pattern of the SCSC using a novel method. (c) PP of the$\Delta B_0$ plotted against current value for the conventional and the novel SCSC. (d) and (e) The coefficients corresponding to fourth and fifth order spherical harmonics expansion of the$\Delta B_0$.