Phantom Results with a Matrix Shim Coil

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Introduction

A resistive shim coil set integrated into a gradient coil is an important tool for high-resolution imaging, especially brain imaging. The traditional high order shim coil is composed of spherical harmonic coils and requires the individual shim coils to have crossing points which will increase the radial build dimensions. The matrix array shim coil [1-2] reduces the radial build dimension requirements and will permit the integration of the matrix array into a smaller radial space. The matrix array shim coil has the potential to offer increased static magnet field corrections over the traditional shim coil design for improved image quality. The shim coils are designed to minimize interactions with the magnet and gradient coils. A 24 channel matrix shim array coil, see Figure 1, was designed and integrated into a wide bore gradient coil to permit resistive shim corrections.
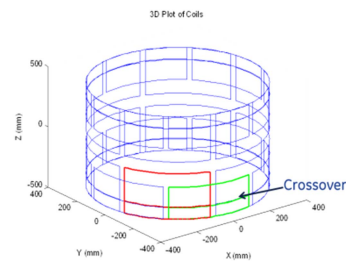

Figure 1. The matrix array shim coil is composed of 24 channels in a 6 x 4 array configuration.

Matrix Shim and Gradient and Magnet Interactions

There are two important considerations when designing the matrix shim array, the interaction with the gradient by inducing voltages and the interaction with the magnet on which determines the switching time. The induced voltages where measured with a slew rate of 120 T/m/s and demonstrate less than ~50 Volts induced by the Z gradient and significantly less, ~10 Volts, by the transverse gradients. Figure 2 shows the measured induced voltages in each channel of the matrix shim coils. The switching time for each shim coil was also measured by tracking the B0 center frequency before and after the switch. The switching time for each channel was measured to be less than ~2 ms without any pre-emphasis. The low switching time allows for dynamic shimming with the matrix shim array.
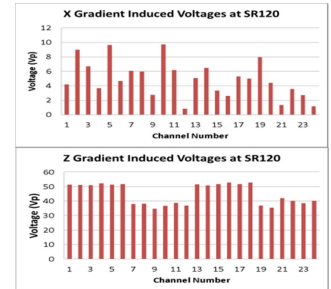

Figure 2. The induced voltages in the matrix shim were measured for the axial and transverse gradients at a slew rate of 120 T/m/s.

Matrix Shim Array Phantom Tests

A 27 cm diameter phantom was placed in a 3T magnet and mated with a 24 Channel Resonance Research (Billerica, MA) driver capable of 24 independent channels of 10 A and 100 V. B0 maps were acquired with the GE MR750w system; twenty slices were acquired with a 256x256 image matrix and 10 mm wide slices. A B0 map was done for each channel of the matrix shim array with 1 ampere of current. Theses calibration files were used in a least-squares fit to minimize the frequency spread of the image. Figure 3 shows the frequency spread for each slice with gradient shimming only (top) and with the matrix shim system (bottom). The required currents to shim the phantom are all less than 1 amp per channel. The frequency spread is shown in Figure 4 for all the slices of the phantom demonstrating the effectiveness of the matrix shim system. The 80% voxel width without shimming is 125 Hz and reduces to 39 Hz with gradient only shimming. The matrix shim system reduces the 80% width to only 11 Hz, a 3 times improvement over gradient only shimming.   Figure 5 shows the potential improvement of dynamic shimming for a single slice, reducing the frequency spread by a factor of 2.
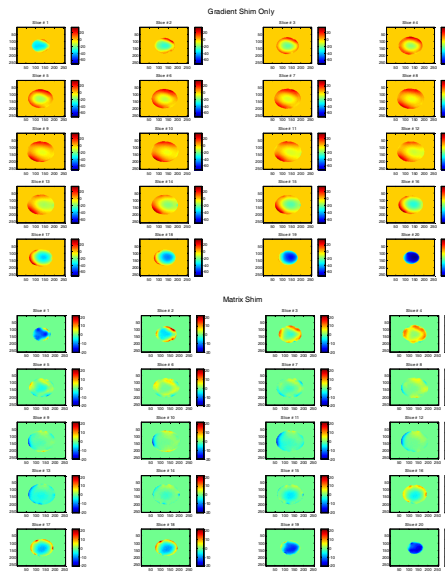

Figure 3. The frequency spread for all 20 slices for gradient only shimming (+30 to -70 Hz) is shown at the top and for matrix shimming on the bottom (+20 to -20 Hz).
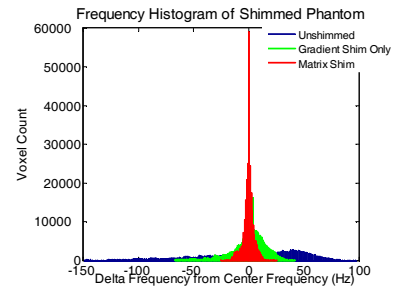

Figure 4. The 80% spectral width for the all 20 slices of the phantom is shown. The width decreases from 125 Hz to 39 Hz for gradient only shimming.   Matrix shimming reduces the width further to 11 Hz.
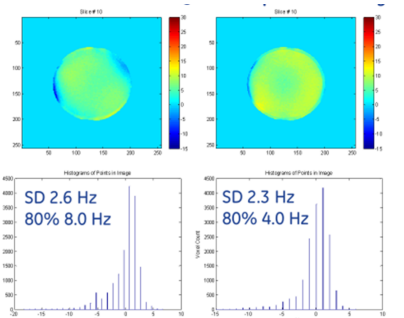

Figure 5. A single slice from the global optimization (left) is compared to an optimized slice (right) resulting in a 2x reduction in frequency spread.

Conclusions

A matrix shim system has been constructed to reduce the frequency spread of the voxels by 3 times as compared to gradient only shimming comprising only ~3 mm of radial space in the gradient. Further work is needed to speed up the calibration scans and improve the optimization of the shim currents.

1.   Seeber, et al. "Matrix Shimming for Whole Body Gradient coils". ISMRM 2012, Melbourne, Australia.
2.   Seeber, et al. "Matrix Shimming for Whole Body Gradient coils". ISMRM 2013, Salt Lake City, Utah, USA.