Refocusing Method for Mapping Imaging Gradients with High SNR

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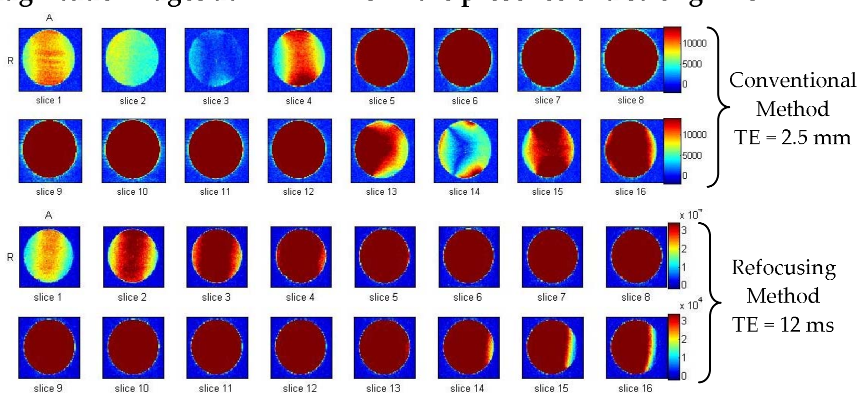
INTRODUCTION: Field mapping of B0 inhomogeneity is commonly performed to correct image distortions during image reconstruction [1] or to set the appropriate shim strengths to create a more uniform backfround field [2]. Field mapping is also important, however, for calibrating the fields produced by shim and imaging gradient coils. Spiral and other non-Cartesian k-space trajectories are especially vulnerable to uncertainty in the strength of the applied gradient fields. Furthermore, the advent of non-linear gradient fields for spatial encoding [3] has opened up the possibility of forming images using dynamically pulsed shim coils. Shim and gradient calibrations are typically performed by applying a narrow range of currents to the coil, obtaining frequency maps, fitting a slope, and then extrapolating the slope over the entire operating range. However, if there are doubts about gradient linearity, the effects of eddy currents, or other factors, it may be advisable to map the fields over as much of their operating range as possible. To prevent the test field from ruining its own field map through excessive spin dephasing, we have modified the conventional field mapping approach to refocus the test field so as to form an echo coincident with the readout gradient being used to create the field map. A high BW is chosen for sampling and thus the phase evolution caused by the test field is slow compared to that of the readout gradient during the echo.

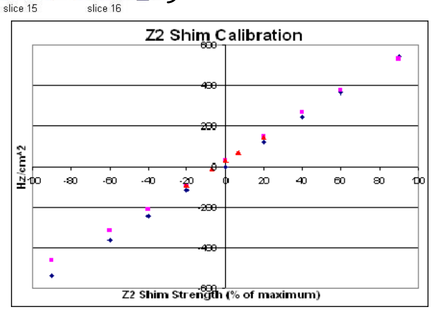
METHODS: Field maps were acquired on a 4.7T Bruker animal magnet operating at 4T (total bore dia. = 310 mm) with a Bruker Avance spectrometer. The Yale system is equipped with a dynamic shimming unit capable of pulsing first order gradients up to roughly 1500 Hz/cm and the Z2 gradient up to 600 Hz/cm^2. The Z2 shim controller is equipped with pre-emphasis to eliminate eddy currents in the cryostat. Gradient echo images are acquired with ΔTE = [0, 0.18, 1, 3] ms. Since $\omega = \Delta\phi/\Delta t$, the phase slope across these four images provides the frequency at each voxel. The first delay is short enough to avoid phase wrapping within the sample. When calculating the slope, the first two points are used to unwrap the phase of the last two points, whose function is to reduce the noise in the slope estimate [2]. For the conventional mapping sequence, TE is set as short as possible to minimize dephasing. For the refocusing method, the minimum possible TE was 12 ms due to the slow rise time (~5 ms) of the shim gradients. FMAP software [4] was used for ROI selection, phase unwrapping, and for calculating the spherical harmonic components present in each field map. The maximum available sampling BW (150 KHz) was used in order to minimize the echo length of the readout gradient, ensuring that the readout echo was temporally far narrower than the shim field echo. A long cylindrical phantom was used to limit initial Z2 inhomogeneity. A spherical ROI was then selected within the phantom to minimize edge effects. The X, Y, and Z2 shims were mapped over a wide operating range.

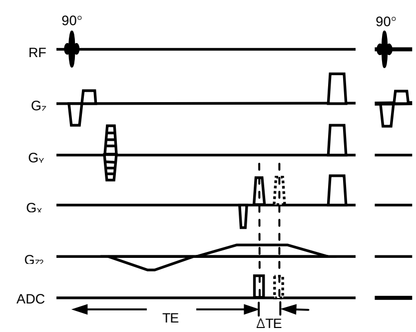
Magnitude Images at ΔTE = 1 ms in the presence of a strong Z2 shim



LEFT: Magnitude images of field mapping data collected on a uniform cylindrical phantom from 16 axial slices, FOV = 4 cm x 4cm x 3.2 cm about z = 0 in the presence of a 540 Hz/cm^2 Z2 field. **BELOW:** Gradient echo field mapping sequence employing dynamic shimming to refocus the Z2 shim field (note the long rise time on the Z2 pulse). **BELOW MIDDLE**: Conventional calibration over narrow range of gradient strengths (■), conventional cal over wide range (▲), and refocusing cal (◆).

Calibrated Slopes (Hz/cm^n/%)			
	X	Y	Z2
Conventional over Narrow Range	-15.47	14.21	5.99
Conventional over Full Range	-15.32	14.20	5.66
Refocusing over Full Range	-15.50	14.11	6.02





DISCUSSION: The refocused field maps suffer from less dephasing than the conventional maps at each ΔTE, yielding more reliable maps over the operating range of the shim coils. The only limitation of the method is that the readout gradient must be substantially stronger than the gradient being mapped. Future work is planned to investigate what this strength difference must be to ensure reliable field maps.

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