Measurement of the Main Field (B_0) Inhomogeneity for the 3T Siemens Magnetom

EEE474 Foundations of Magnetic Resonance Imaging
Project Presentation
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Introduction

Off-Resonance Sources [1]

- Main Field Inhomogeneity
- Susceptibility-Induced Field Variations
- Chemical Shift

How does it affect the imaging?

- Signal Intensity Loss
- Distortions and Blurring
- Curved Slice Profiles [2]

Shading Artifact due to the Main Field Inhomogeneity [3]

Introduction

How can we quantify the field inhomogeneity?

The phase accumulated by a spin is proportional to the main field:

$$\phi = \gamma(B0 + \Delta B)\, TE$$

If we acquired 2 scans (at least) with different echo times

$$\Delta\phi = \gamma(\Delta B)\, (TE2 - TE1)$$

$$\Delta B = \frac{\Delta\phi}{\gamma(TE2 - TE1)}$$

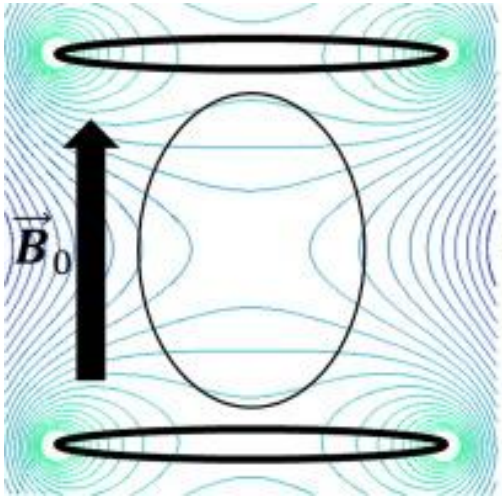


Illustration of B_0

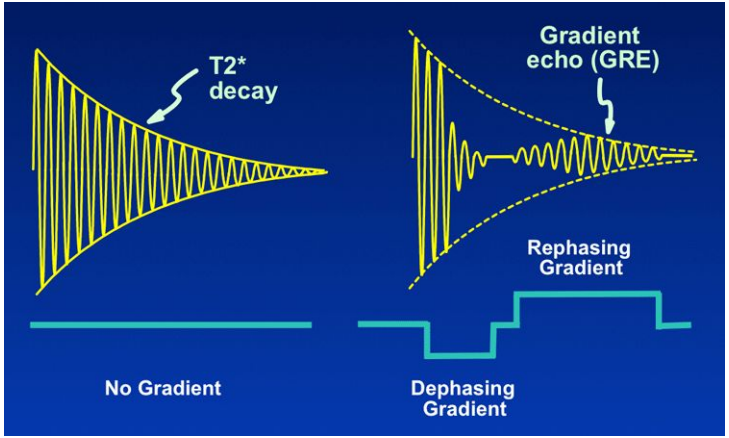
Methodology: Pulse Sequence Selection

Gradient Echo pulse sequences are more effective for constructing field maps!

- ➔ Only one RF pulse is applied :

  Rapid acquisition and reduced scan time.
- ➔ Gradient reversal is applied:

  Phase shift due to the field inhomogeneity is detectable [4].



From FID to GRE by Applying Gradient Reversal

Methodology : GRE Acquisitions and Setup

Separate scans were acquired using a labeled GRE at 3 echo times

TE1 = 5ms

TE2 = 12ms

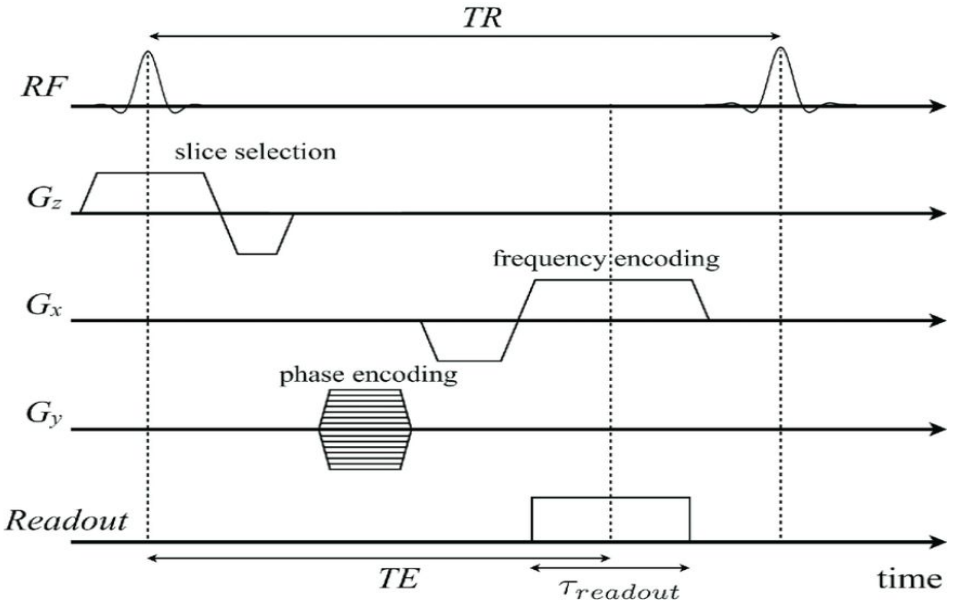
TE3 = 20ms

Other parameters:

TR = 100ms

Flip angle = 10 degrees

Resolution = 256x256



Gradient Echo Sequence Timing Diagram

Methodology: Combining Array Coil Signals

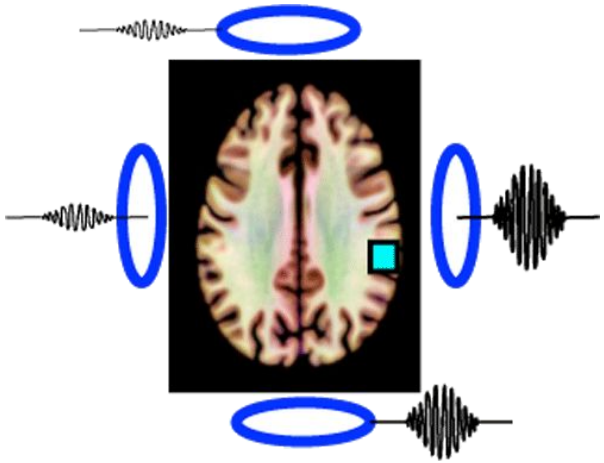
A Siemens 32-channel coil was used to receive the data

➔ Increase the signal-to-noise (SNR) ratio [5]

Magnitude images are combined using sum of squares (SoS)

Phase images can be averaged ***but*** phase is wrapped

➔ Solution: work with phase difference between TE's



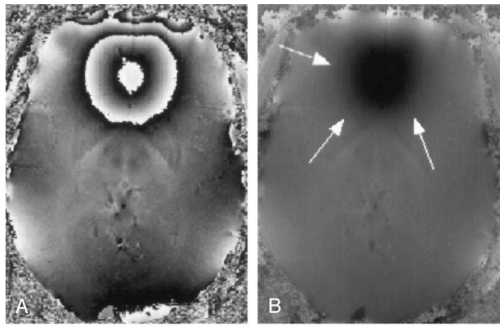
Parallel Imaging Using Multiple Coils

Methodology: Phase Unwrapping

Matlab built-in function does not support 2D unwrapping

➔ Fast two-dimensional phase unwrapping algorithm based on sorting by reliability [6]

- Robustness : handles phase discontinuities better than traditional methods
- Efficient : fast processing (∼0.5 seconds) for typical images
- Effective: proven through real-world tests to manage noisy data



Methodology: B0 Field Map Generation

The phase evolution between 2 echos:

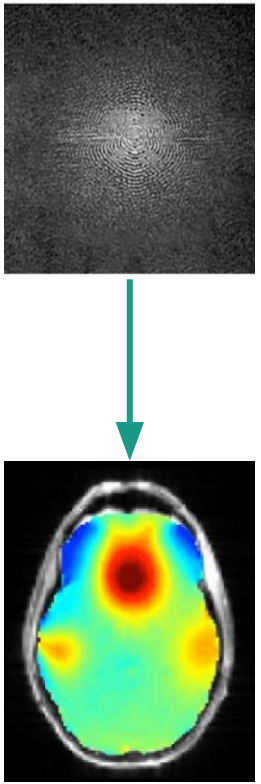
$$\Theta\left(\vec{r}, n, m\right) = \angle\left[\sum_{j} I_j\left(\vec{r}, TE_n\right) I_j\left(\vec{r}, TE_m\right)\right]$$

Weighting factor to construct the field map:

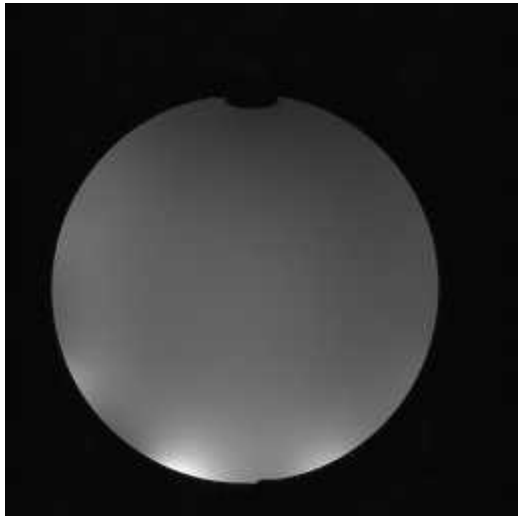
$$W(\vec{r}, k) = \frac{M(\vec{r}, k)^2}{M(\vec{r}, k)^2 + M(\vec{r}, 1)^2}$$

The B0 field map [5]:

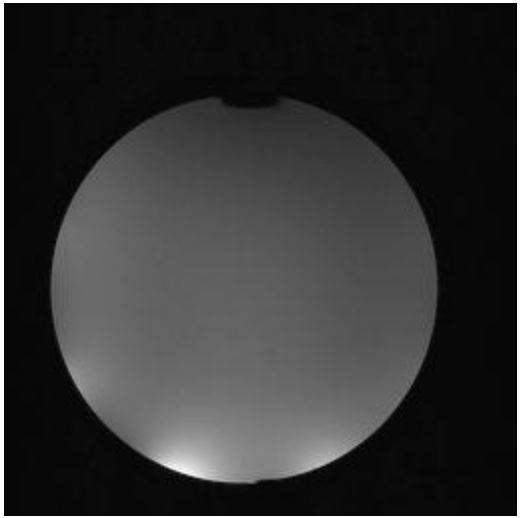
$$\Delta B(\vec{r}) = \frac{1}{2\pi\gamma} \frac{\sum_{k=2}^{K} \Theta(\vec{r}, n, m)\left(TE_k - TE_1\right).W(\vec{r}, k)}{\sum_{k=2}^{K}\left(TE_k - TE_1\right)^2.W(\vec{r}, k)}$$



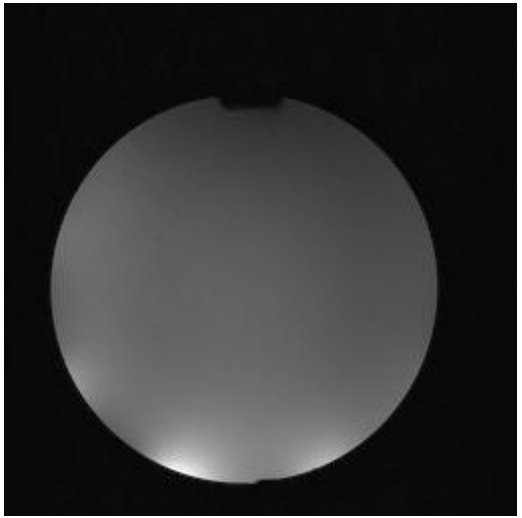
Results: Magnitude Images



Acquisition with TE1 (5ms)

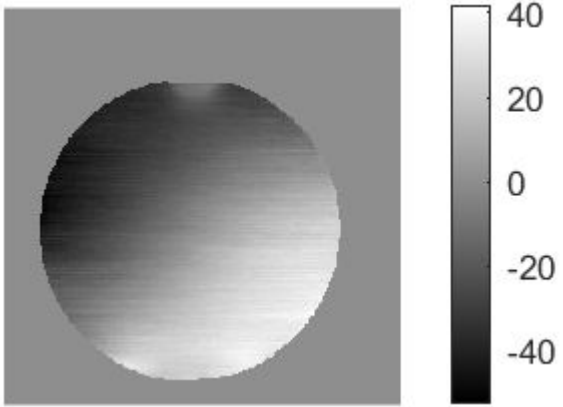


Acquisition with TE2 (12ms)

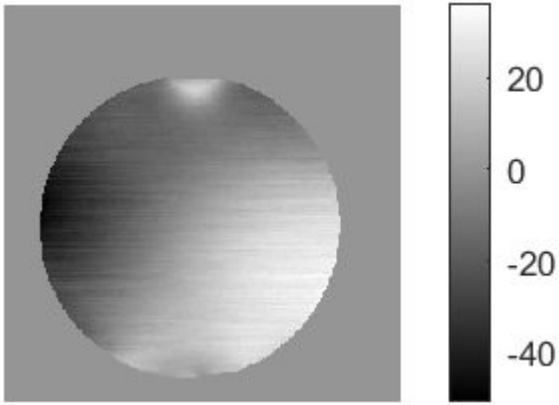


Acquisition with TE3 (20ms)

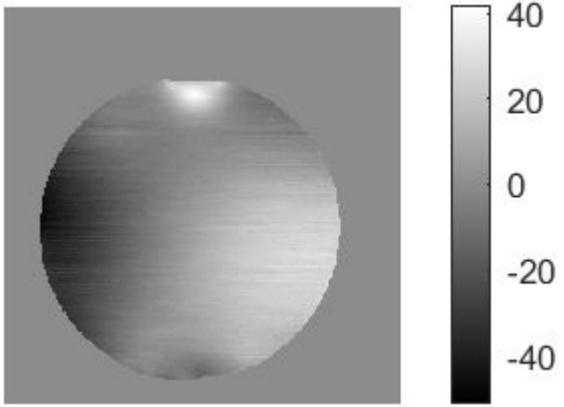
Results: Phase Images



Acquisition with TE1 (5ms)

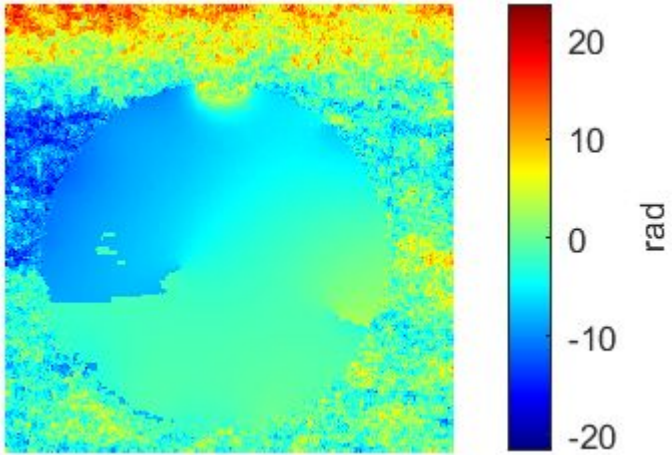


Acquisition with TE2 (12ms)

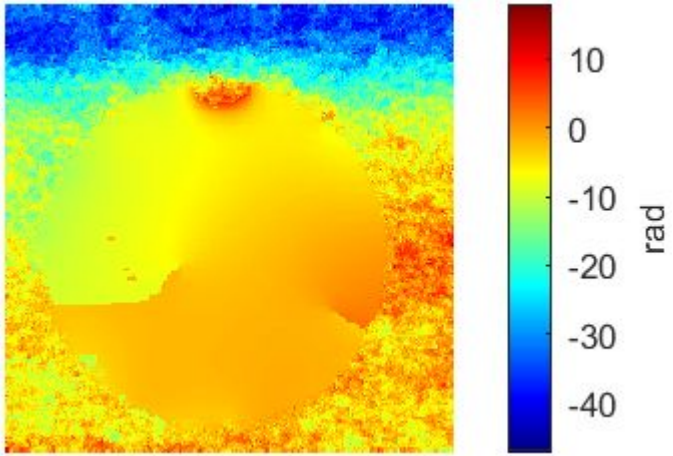


Acquisition with TE3 (20ms)

Results: Phase Evolution



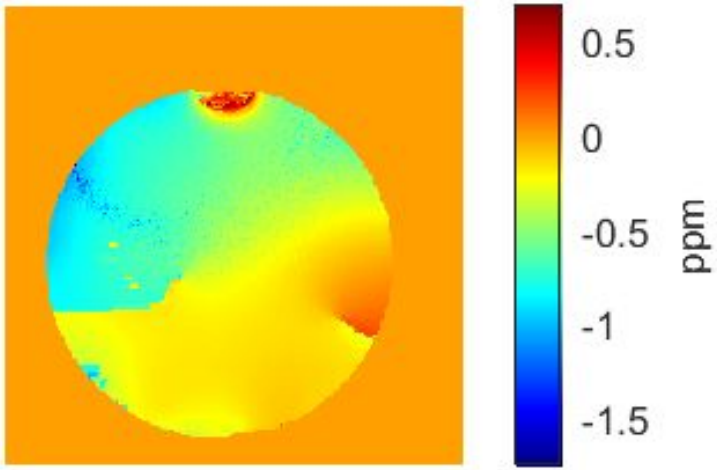
Phase Map (TE1, TE2)



Phase Map (TE1, TE3)

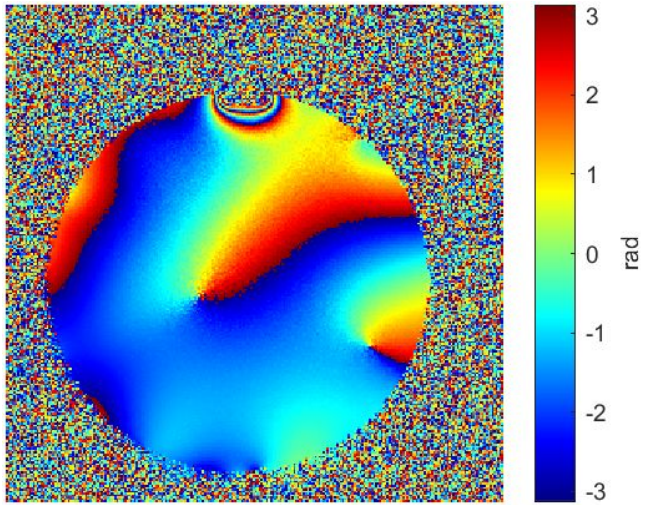
Results: B0 Field Map

B0 = 3T
ΔB = [-5 , 2] μT
ΔB = [-1.5, 0.5] ppm

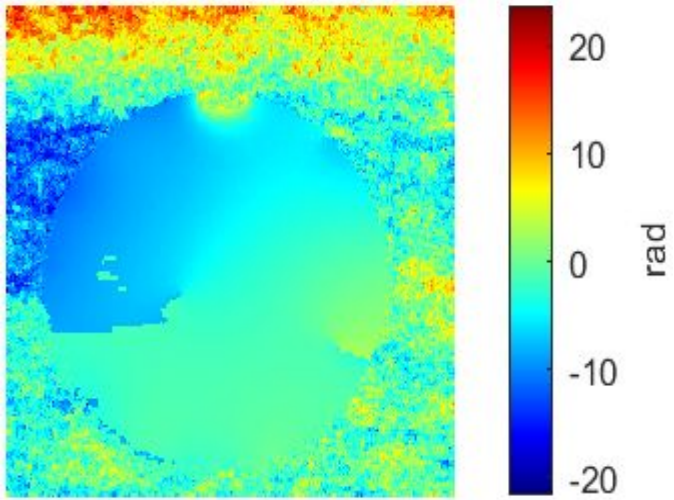


B0 Field Map (Masked)

Discussion: Wrapped vs. Unwrapped



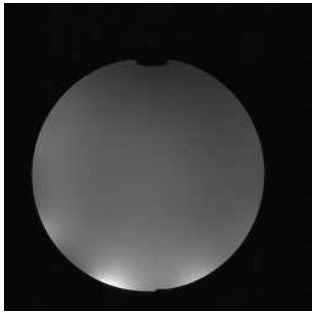
Phase Map (Wrapped)



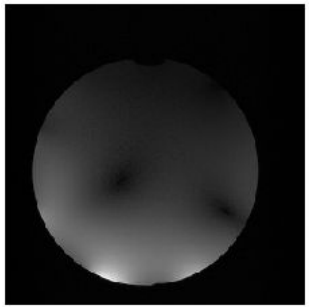
Phase Map (Unwrapped)

Discussion: Improvements

- ➔ Acquiring the phase maps directly from the scanner
- ➔ Using the FSL toolbox to unwrap the phase
- ➔ Optimized choice of echo times
- ➔ Incorporating the coil sensitivity in the reconstruction



Scanner Reconstruction



SoS Reconstruction

References

[1] D. G. Nishimura, *Principles of Magnetic Resonance Imaging*, 1.1st ed. Lulu, 2010, pp. 127-128.

[2] M. W. Haskelon, J.-F. Nielsen, and D. C. Noll, "Off-resonance artifact correction for MRI: A review," *NMR in Biomedicine*, vol. 36, 2023. doi: 10.1002/nbm.4867.

[3] “Importance of Field Homogeneity,” *Questions and Answers in MRI*. [Online] Available: https://mriquestions.com/why-homogeneity.html.

[4] “GRE v SE,” *Questions and Answers in MRI*. [Online] Available: https://www.mriquestions.com/gre-vs-se.html.

[5] S. D. Robinson, K. Bredies, et al., “An illustrated comparison of processing methods for MR phase imaging and QSM: combining array coil signals and phase unwrapping,” *NMR in Biomedicine*, vol. 30, 2016, doi: https://doi.org/10.1002/nbm.3601.

[6] M. A. Herráez, D. R. Burton, M. J. Lalor, and M. A. Gdeisat, “Fast two-dimensional phase-unwrapping algorithm based on sorting by reliability following a noncontinuous path,” *Applied Optics*, vol. 41, no. 35, p. 7437, Dec. 2002, doi: https://doi.org/10.1364/ao.41.007437.