Vendor-specific approaches to $B_0$ homogeneity testing

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What we’ll cover

• Homogeneity **OVERVIEW**

• An introduction to the main **METHODS** of measuring $B_0$ homogeneity

• Step-by-step **PROCEDURES** for $B_0$ homogeneity measurement on different vendor platforms (1-2 methods per vendor)

• **RESOURCES** for more information about theory and implementation of different $B_0$ homogeneity testing methods
Contributors

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Sam Fielden
**B₀ inhomogeneity** (\(\Delta B₀\))

- Measure of static magnetic field strength uniformity

- Influenced by
  - Magnet design & manufacturing
  - External ferromagnetic structures
  - Shim compensation
  - Phantom or patient in magnet

- Influences
  - Chemical shift techniques: fat suppression (SPIR, SPAIR)
  - Spectroscopy techniques
  - Geometric distortion
  - Signal uniformity
  - Banding artifacts
**B₀ inhomogeneity** \((\Delta B₀)\)

- Measure of static magnetic field strength uniformity
  - Variation over a specified volume (DSV)
  - Expressed in ppm or Hz
  - **RMS** measurement of B₀ inhomogeneity is volume-averaged
  - **Peak-to-peak** requires a spatial measurement of variations
**Spectral peak**

\[ S(t) = M_0 \sin(w_0 t)e^{-\frac{t^2}{r_0^2}} \]

\[ \Delta B_{0, \text{rms}} \text{ (ppm)} = \frac{\text{FWHM (Hz)}}{\gamma \left( \frac{\text{MHz}}{T} \right) \times B_0(T)} \]

\[ \gamma = 42.56 \text{ MHz/T} \]

**Notes**

+ quick and simple
- no spatial information

- Global measure: \( B_{0, \text{rms}} \) only, not \( B_{0, \text{pp}} \)
- DSV determined by phantom

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**OVERVIEW**

**METHODS**

**PROCEDURES BY VENDOR**

**RESOURCES**
Phase difference & phase map

\[ \Delta \varphi_{pp} = \frac{ROI_{\text{max}} - ROI_{\text{min}}}{DR_{ADC}} \]

\[ \Delta \varphi_{\text{rms}} = \sqrt{\frac{ROI_{\text{mean}}^2 + ROI_{\text{stdev}}^2}{DR_{ADC}}} \]

\[ \Delta B_0 \text{ (ppm)} = \frac{\Delta \varphi}{\gamma B_0 \times \Delta TE} \]

Phase difference & phase map

Notes
+ can perform in 3D (or 3 orthogonal planes)
+ includes spatial information
- phase image accessibility
- phase wraps
- analysis on scanner can be difficult

- $B_{0,rms}$ or $B_{0,pp}$
- DSV determined by ROI (user-selectable within phantom)
- A single phase map can also be used to estimate upper bound of $\Delta B_0$

ACR 2015 MRI Quality Control Manual
Field map

- If available, this is a straightforward vendor-provided capability
- 3D map acquired or created from 2D maps
- Comparable results to phase difference mapping
Bandwidth difference

\[ \Delta B_0 \text{(ppm)} = \frac{BW_1 \times BW_2 \times (x_1 - x_2)}{\gamma B_0 \times FOV \times (BW_2 - BW_2)} \]

(BW in Hz)

Notes
- accessible on all platforms
- many acquisitions & measurements for 3D evaluation
- assumes proper gradient calibration

\[ \Delta B_0 = 1.16 \text{ ppm @ 19 cm Diameter} \]

BW\(_1 = 6 \text{ Hz/pixel}\)

BW\(_2 = 160 \text{ Hz/pixel}\)

ACR 2015 MRI Quality Control Manual
Procedures by vendor

- Step-by-step instructions/button-ology
- Variation by software version, but this should provide a solid starting point
- Talk to vendor field engineer if you need guidance on your specific system
Accessible field map function: Large Volume (LV) shim
Phantom: 45 cm diameter LV shim phantom*
Coil: body coil

Calibration → Calibration tools → LV shim → “Click here to start this tool” → Test → Scan

*no matter the phantom or procedure, let it rest a few minutes so fluid can settle
GE: LV shim results

<table>
<thead>
<tr>
<th>pp or rms</th>
<th>result</th>
<th>spec</th>
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<tbody>
<tr>
<td>x48 p2p</td>
<td>24.417</td>
<td>NA</td>
</tr>
<tr>
<td>x45 p2p</td>
<td>12.013</td>
<td>15.00</td>
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<tr>
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<tr>
<td>x45 rss</td>
<td>3.443</td>
<td>NA</td>
</tr>
<tr>
<td>x40 rss</td>
<td>1.604</td>
<td>15.00</td>
</tr>
<tr>
<td>x30 rss</td>
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</tr>
<tr>
<td>x40 rss</td>
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<td>0.60</td>
</tr>
<tr>
<td>x20 rss</td>
<td>0.114</td>
<td>0.30</td>
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</table>

OVERVIEW

METHODS

PROCEDURES BY VENDOR

RESOURCES
GE: Other options

Spectral peak in manual pre-scan

Bandwidth difference

CV rhrcctrl = 3 for magnitude and phase (31 for magnitude, phase, real, imaginary)
Siemens: Phantom shim check procedure

- Accessible field map function: Phantom shim check
  - Requires a service password which is typically easily obtained
- Phantom: 24 cm homogenous sphere
- Coil: Body

\[\text{Hit “Go”}\]
Siemens: Phantom shim check results
Siemens: Other options

BW difference is generally accessible

\[ \Delta B_0 \text{ (ppm)} = \frac{BW_1 \times BW_2 \times (x_1 - x_2)}{\gamma \times B_0 \times FOV \times (BW_2 - BW_2)} \]

BW in Hz – multiply Hz/pixel by number of pixels in FE direction

Spectral peak (newer systems)

- After localizer, while setting up another protocol, System → Adjustments → Confirm frequency adjustment
- After pre-scan begins, spectrum displayed
- FWHM displayed or estimate by moving vertical line
Philips: Shim check procedure

- Accessible field map function: Shim check
- Phantom: 40 cm disk
- Coil: Body

Phantom studies → MISC

<table>
<thead>
<tr>
<th>Sequence</th>
<th>FFE</th>
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<tbody>
<tr>
<td>TR</td>
<td>400 ms</td>
</tr>
<tr>
<td>TE</td>
<td>16 ms</td>
</tr>
<tr>
<td>FA</td>
<td>30°</td>
</tr>
<tr>
<td>FOV</td>
<td>45 cm</td>
</tr>
</tbody>
</table>
Philips: Shim check results

- Each B→W transition is 1.0ppm. (1 full cycle is 1.0 ppm)
- Count number $N$ of B→W transitions, $\Delta B_{0,pp} = N \times 1.0\, ppm$
- Re-position phantom and run in 3 planes
After running non-survey scan
Examination ➔ Data Monitoring ➔
F0 ➔ Show Latest
Zoom in on half of Y Maximum to estimate FWHM

**Spectral peak**

**BW difference**
- Older systems display fat-water shift in pixels instead of bandwidth/pixel
- Calculate Hz/pixel:
  \[
  \frac{Hz}{\text{pixel}} = \frac{3.5\text{ppm} \times \gamma \left(\frac{MHz}{T}\right) \times B_0(T)}{\text{fat – water shift (pix)}}
  \]

**Phase difference map**
- Phase images can be reconstructed also by selecting M (magnitude) and P (phase) on Postproc ➔ Images on the exam card.
- Use image algebra in viewing environment to subtract
- If necessary, reduce TE difference to reduce phase wraps

**Field mapping**
- SPT tools can be used with a service dongle
Toshiba/Canon: Phase difference procedure

- Phantom: 30 cm spherical
- Coil: Body
- Protocol: FE_AAS

Run in axial plane

Image selector window
Toshiba/Canon: Phase difference results

- Repeat in sagittal and coronal planes
- Field homogeneity (within DSV = ROI diameter) is the absolute max pixel value found in the ROI in any plane
- Absolute pixel value of 100 corresponds to 1 ppm
Hitachi: Fine magnetic field analysis set-up

- Oasis & Echelon
- Phantom: Bottle 11
- Coil: RAPID body (Oasis) or T/R Body (Echelon)
- Protocol: Fine magnetic field analysis tool

**Oasis**

- RAPID body coil, laterally centered, no pads (required for valid results)
- Align laser with phantom landmarks, not coil

**Echelon**

- Align to phantom landmark lines
- Pad A or C on tabletop
Hitachi: Fine magnetic field analysis results

- Hitachi recommends service call if >1.0ppm for Shim On and >5.0 ppm for Shim Off
- ROI placement is automatic – very sensitive to lateral positioning!
**Hitachi: SHIM procedure**

- **AIRIS, Altaire**
- **Phantom:** #4 bottle (AIRIS) or D bottle (Altaire)
- **Coil:** Head

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**SNR analysis card – place measurement ROIs and record Max and Min for each slice**

<table>
<thead>
<tr>
<th>Slice Number</th>
<th>Slice position (mm)</th>
<th>ROI diameter (mm)</th>
</tr>
</thead>
<tbody>
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<td>-70</td>
<td>110</td>
</tr>
<tr>
<td>2</td>
<td>-60</td>
<td>134</td>
</tr>
<tr>
<td>3</td>
<td>-50</td>
<td>150</td>
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<td>134</td>
</tr>
<tr>
<td>15</td>
<td>70</td>
<td>110</td>
</tr>
</tbody>
</table>

**Calculate $\Delta B_{0,pp}$ for each slice:**

- **AIRIS:** $\Delta B_0 = 0.114$ ppm * Max(Re) – Min(Re)
- **AIRIS Elite:** $\Delta B_0 = 0.104$ ppm * Max(Re) – Min(Re)
- **Altaire:** $\Delta B_0 = 0.068$ ppm * Max(Re) – Min(Re)

**Determine largest $\Delta B_{0,pp}$ value among all slices from each of three planes and compare to specifications:**

- **AIRIS:** $\Delta B_0 \leq 1.5$ ppm
- **AIRIS Elite:** $\Delta B_0 \leq 1.5$ ppm
- **Altaire:** $\Delta B_0 \leq 1.75$ ppm

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**RESOURCES**
Fonar: Field map procedure

- Accessible field map function
- Phantom: 19 cm soccer ball!
- Coil: 45 inch torso belt coil
Fonar: Field map results

- Echo spacing such that phase wraps are 1.0ppm apart
- Center of volume always scaled to middle of greyscale range
More Resources: AAPM Report 100

- Details sources and impacts of poor homogeneity
- Overview of 3 measurement methods
- Advantages and disadvantages of each
- Suggested acceptance criteria for routine and ultrafast imaging

https://www.aapm.org/pubs/reports/RPT_100.pdf
More Resources: ACR MRI QC Manual

- ACR-specific requirements for $B_0$ testing
- General theory behind homogeneity testing
- Detailed vendor agnostic descriptions of 4 measurement methods
- Suggested corrective action

• **Bandwidth difference method:** Chen HH, Boykin RD, Clarke GD, Gao JHT, Roby JW. Routine testing of magnetic field homogeneity on clinical MRI systems. *Med Phys* 2006 33(11)
More Resources

- **TG325 resources** on AAPM website should be live now or soon – likely under “Publications” on AAPM site

- **Interactive poster session:**
  - Thursday 7/29 3-3:30PM
  - Imaging: MRI Physics and QC
  - *Dependence of $B_0$ homogeneity on field strength and phantom size when measured with four common methods* – Travis Salzillo et al