

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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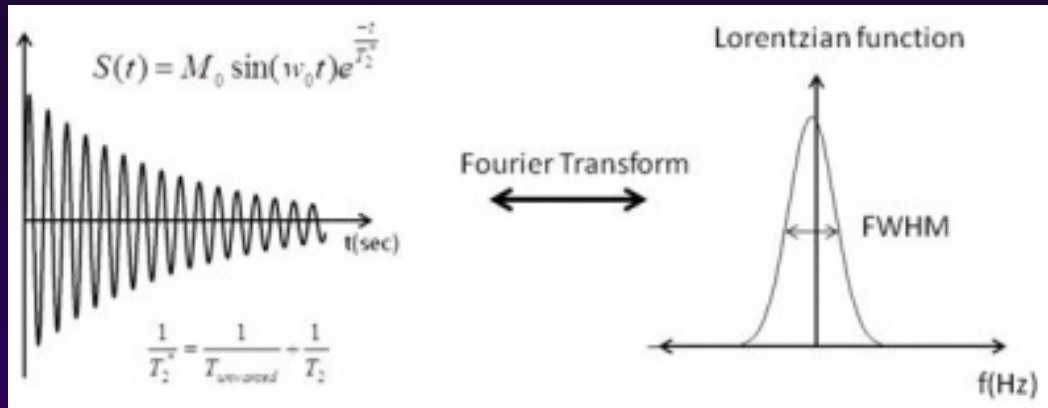
Kathryn Huff

Jessica Saunders

B_0 inhomogeneity (ΔB_0)

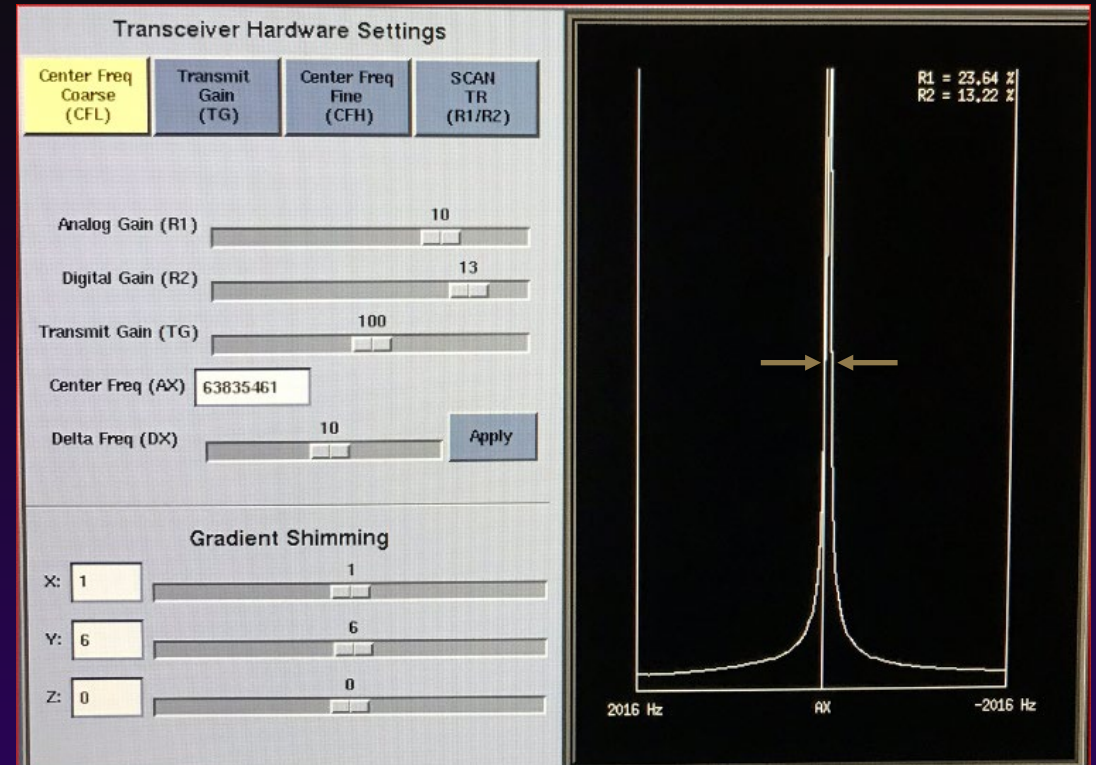
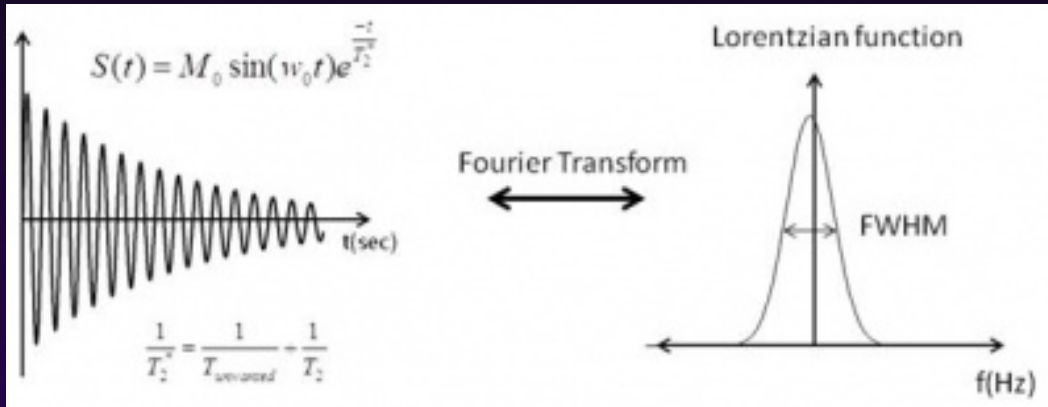
- Measure of static magnetic field strength uniformity
- Influenced by
 - › Magnet design & manufacturing
 - › External ferromagnetic structures
 - › Shim compensation
 - › Phantom or patient in magnet
- Influences
 - › Chemical shift techniques: fat suppression (SPIR, SPAIR)
 - › Spectroscopy techniques
 - › Geometric distortion
 - › Signal uniformity
 - › Banding artifacts

B_0 inhomogeneity (ΔB_0)



- Measure of static magnetic field strength uniformity
 - › Variation over a specified volume (DSV)
 - › Expressed in ppm or Hz
 - › **RMS** measurement of B_0 inhomogeneity is volume-averaged
 - › **Peak-to-peak** requires a spatial measurement of variations

Spectral peak



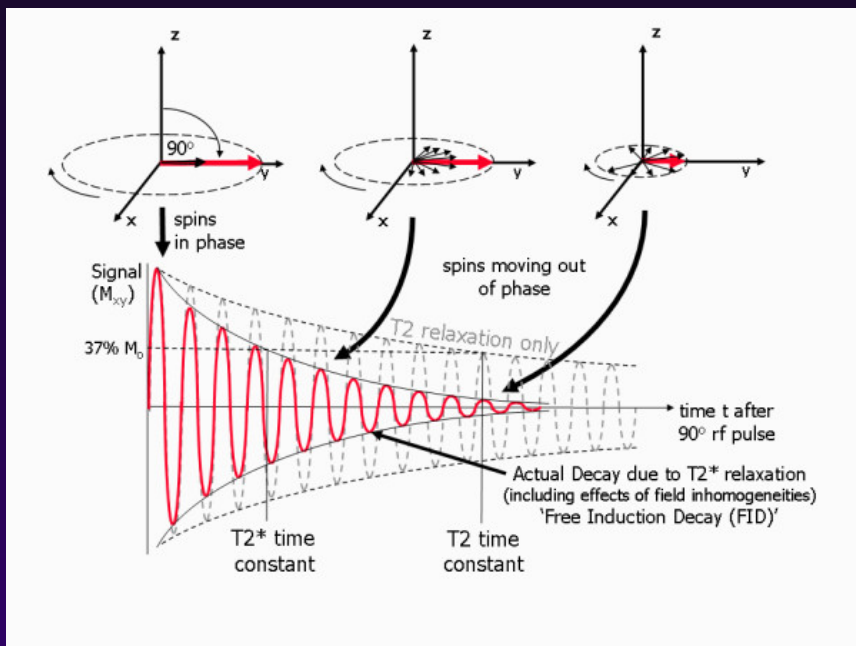
Notes

- + quick and simple
- no spatial information
- Global measure: $B_{0,rms}$ only, not $B_{0,pp}$
- DSV determined by phantom

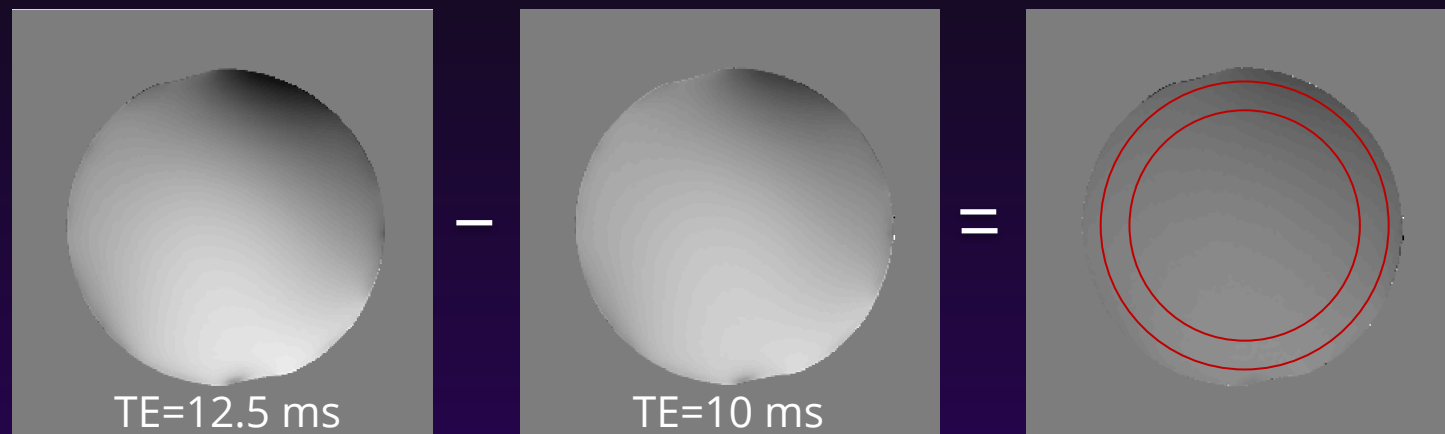
$$\Delta B_{0,rms} (ppm) = \frac{FWHM (Hz)}{\gamma \left(\frac{MHz}{T} \right) \times B_0(T)}$$

$$\gamma = 42.56 \text{ MHz/T}$$

Phase difference & phase map



Ridgway JP. *J Cardivasc Magn Reson* 2010. 12(1):71.



$$\Delta\phi_{pp} = \frac{ROI_{max} - ROI_{min}}{DR_{ADC}}$$

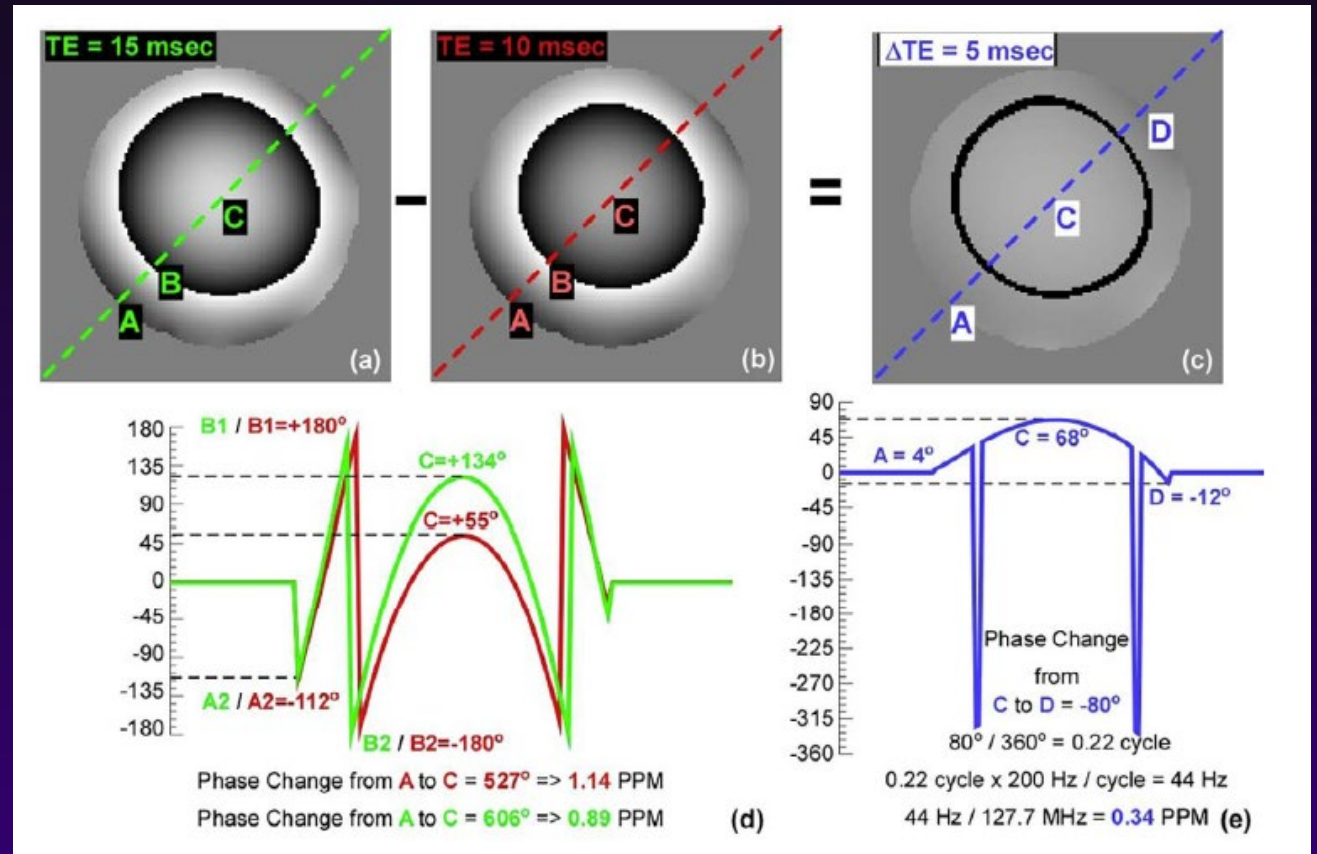
$$\Delta\phi_{rms} = \frac{\sqrt{ROI_{mean}^2 + ROI_{stdev}^2}}{DR_{ADC}}$$

$$\Delta B_0 \text{ (ppm)} = \frac{\Delta\phi}{\gamma B_0 \times \Delta TE}$$

Phase difference & phase map

Notes

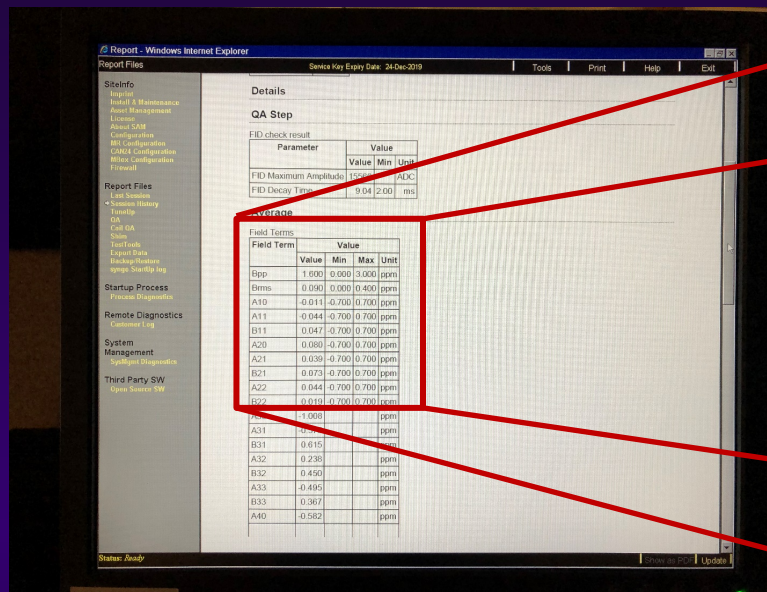
- + can perform in 3D (or 3 orthogonal planes)
 - + includes spatial information
 - phase image accessibility
 - phase wraps
 - analysis on scanner can be difficult
-
- $B_{0,rms}$ or $B_{0,pp}$
 - DSV determined by ROI (user-selectable within phantom)
 - A single phase map can also be used to estimate upper bound of ΔB_0



ACR 2015 MRI Quality Control Manual

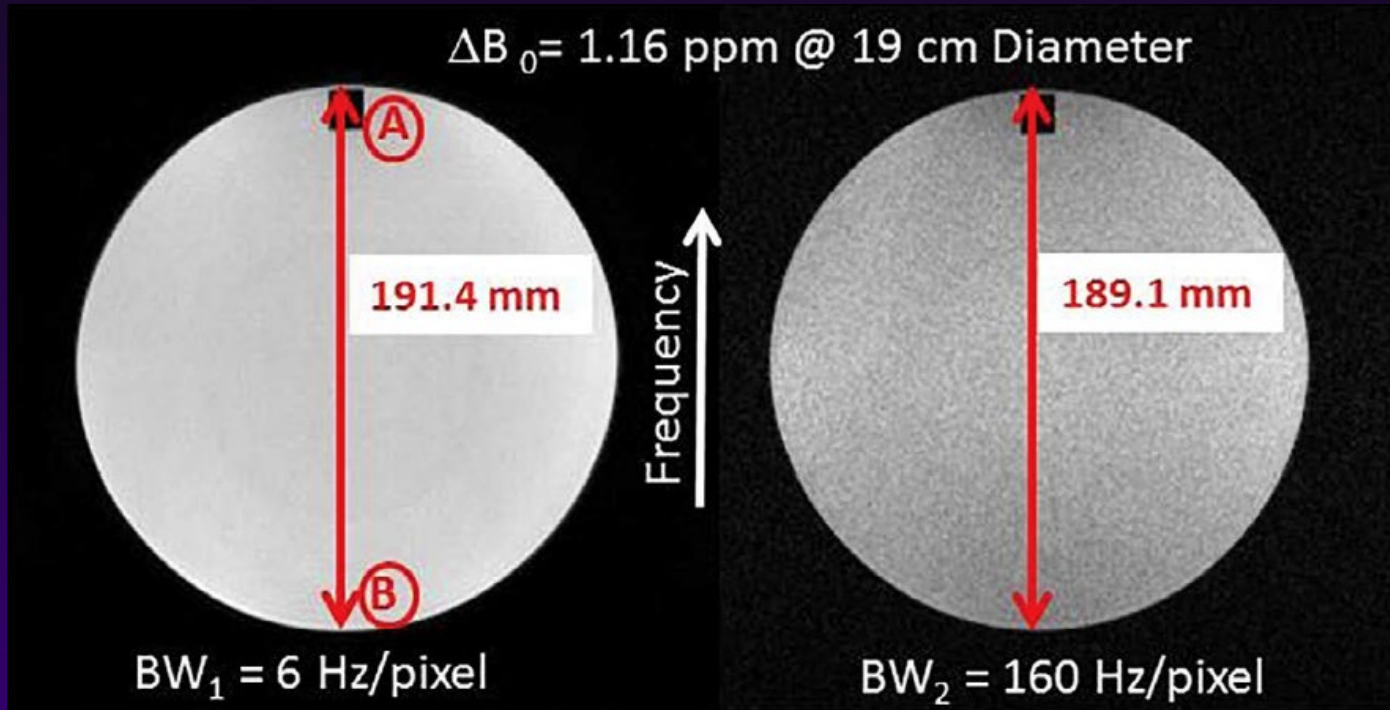
Field map

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



Field Terms				
Field Term	Value			
	Value	Min	Max	Unit
Bpp	1.600	0.000	3.000	ppm
Brms	0.090	0.000	0.400	ppm
A10	-0.011	-0.700	0.700	ppm
A11	-0.044	-0.700	0.700	ppm
B11	0.047	-0.700	0.700	ppm
A20	0.080	-0.700	0.700	ppm
A21	0.039	-0.700	0.700	ppm
B21	0.073	-0.700	0.700	ppm
A22	0.044	-0.700	0.700	ppm
B22	0.019	-0.700	0.700	ppm

Bandwidth difference



ACR 2015 MRI Quality Control Manual

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

(BW in Hz)

Notes

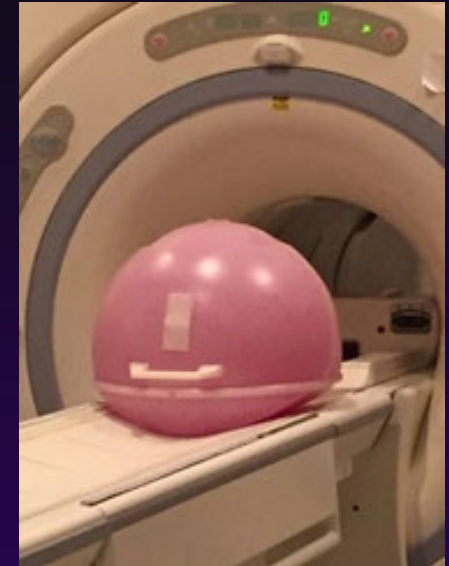
- + accessible on all platforms
 - many acquisitions & measurements for 3D evaluation
 - assumes proper gradient calibration
-
- DSV determined by phantom or internal markers

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

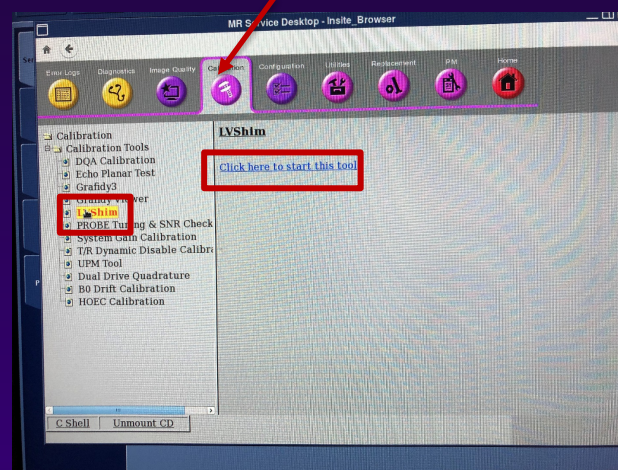
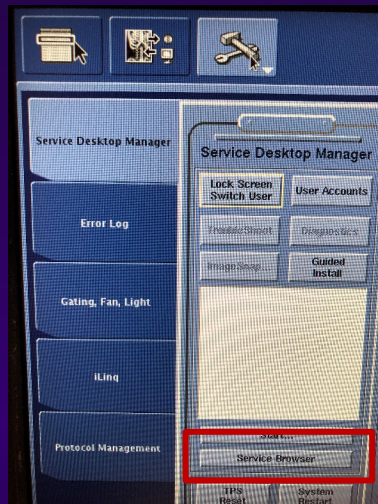
GE: LV shim procedure

- 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

Shim Type for 3.0T Wide Bore
Gradient Shim

Auto/Manual Mode
Auto Mode Max Iter's
Manual Mode

Current E/S/I
Exam 50644
Series 1
Image

0)/Z1	Initial Current	Scan 1
0)/Z2	-0.30 [NA]	
0)/Z3	39.05 [NA]	
0)/Z4	21.58 [NA]	
0)/Z5	-44.97 [NA]	
0)/Z6	-28.74 [NA]	
0)/Z6	-29.51 [NA]	
1)/X	-0.06 [NA]	
-1)/X	-1.46 [NA]	
1)/ZY	-8.10 [NA]	
-1)/ZY	-2.53 [NA]	
2)/Y2-Y2	-25.17 [NA]	
-2)/Y2	12.05 [NA]	
1)/ZX	-5.34 [NA]	
-1)/ZX	36.88 [NA]	
2)/Y2-Y2	10.88 [NA]	
-2)/Y2	-6.57 [NA]	
2)/Y3	-19.16 [NA]	
-2)/Y3	-6.54 [NA]	
x48 p2p (ppm)	24.417 [NA]	
x45 p2p (ppm)	12.013 [15.00]	
x40 p2p (ppm)	4.049 [6.00]	
x30 p2p (ppm)	0.795 [2.00]	
x20 p2p (ppm)	0.294 [1.00]	
x48 rms (ppm)	1.116 [NA]	
x45 rms (ppm)	0.585 [1.25]	
x40 rms (ppm)	0.231 [1.00]	
x30 rms (ppm)	0.091 [0.50]	
x20 rms (ppm)	0.040 [0.10]	
id shim: X/Y/Z	5 -11 -1	
width	45	
is type	Test	

Scan Abort Exit

pp
or
DSV rms

result spec

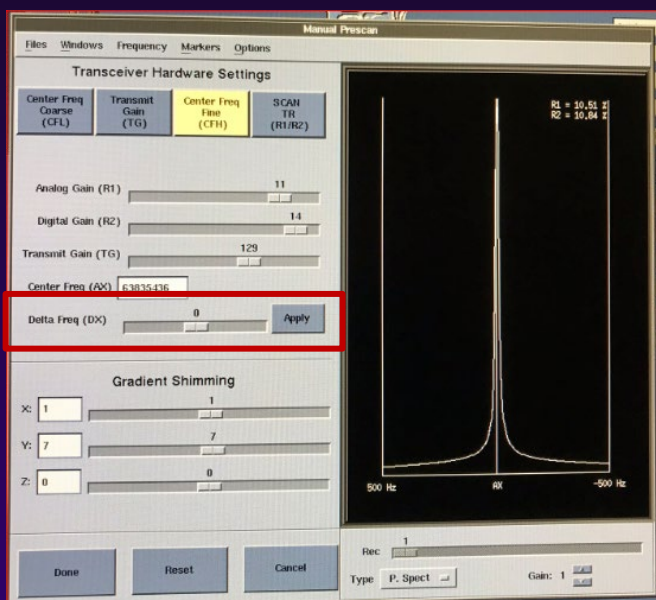
-3)/Y3

x48 p2p (ppm)	24.417 [NA]
x45 p2p (ppm)	12.013 [15.00]
x40 p2p (ppm)	4.049 [6.00]
x30 p2p (ppm)	0.795 [2.00]
x20 p2p (ppm)	0.294 [1.00]
x48 rms (ppm)	1.116 [NA]
x45 rms (ppm)	0.585 [1.25]
x40 rms (ppm)	0.231 [1.00]
x30 rms (ppm)	0.091 [0.50]
x20 rms (ppm)	0.040 [0.10]
id shim: X/Y/Z	5 -11 -1

	-0.53 [NA]
	23.443 [NA]
	11.604 [15.00]
	4.886 [6.00]
	1.321 [2.00]
	0.580 [1.00]
	0.973 [NA]
	0.604 [1.25]
	0.340 [1.00]
	0.195 [0.50]
	0.114 [0.10]
-1	-----
	50645/1/1
	45
	400
	Test

GE: Other options

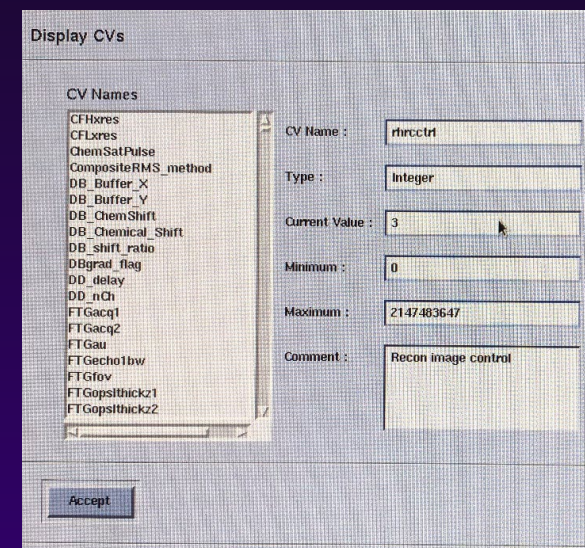
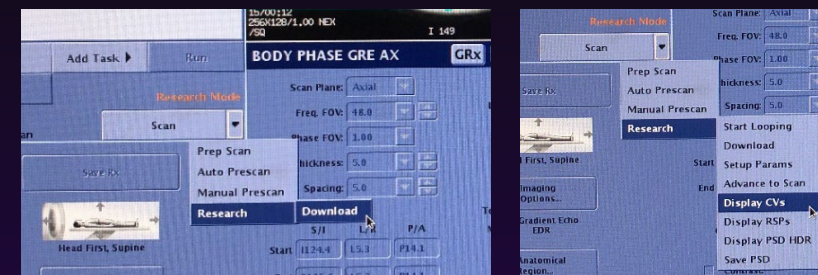
Spectral peak in manual pre-scan



Bandwidth difference



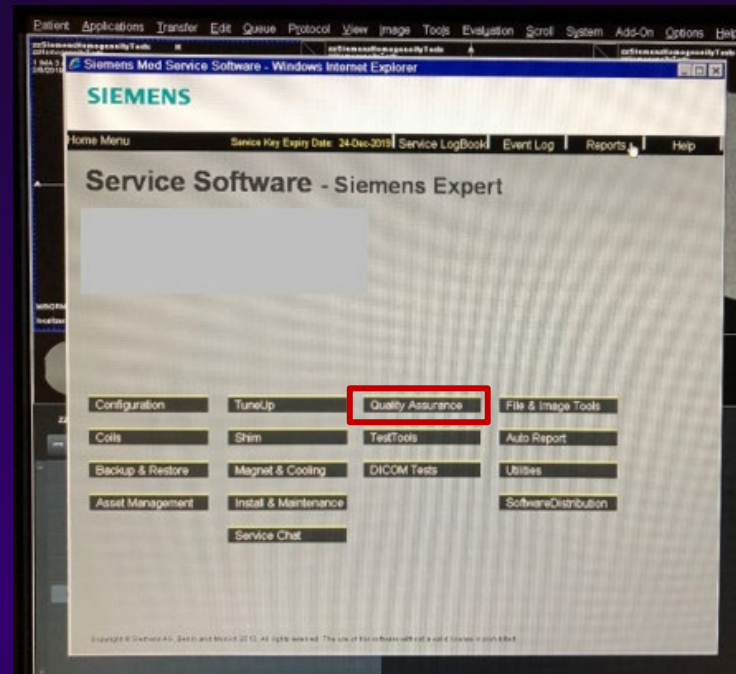
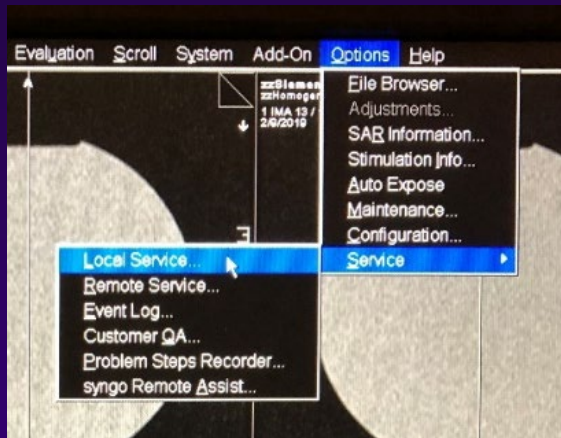
Phase difference



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

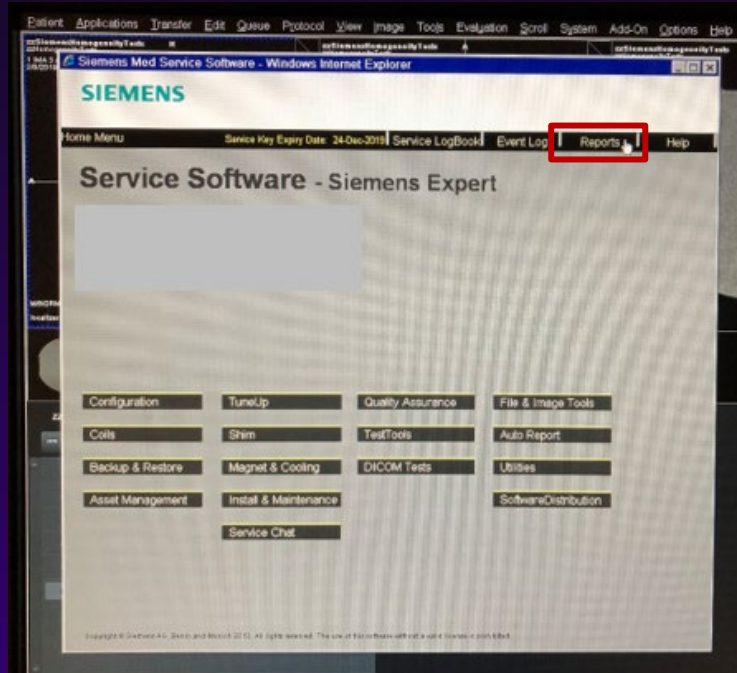


Quality Assurance → Phantom Shim Check



→ Hit "Go"

Siemens: Phantom shim check results



Report - Windows Internet Explorer

Service Key Expiry Date: 24-Dec-2019

Tools | Print | Help | Exit

Report Files

SiteInfo

Imprint

Install & Maintenance

Asset Management

License

About SAM

Configuration

MR Configuration

CAN24 Configuration

MRBox Configuration

Firewall

Report Files

Last Session

Session History

QA

Coil QA

Shim

TestTools

Expert Data

Backup/Restore

syngo StartUp log

Startup Process

Process Diagnostics

Remote Diagnostics

Customer Log

System Management

SysMgmt Diagnostics

Third Party SW

Open Source SW

Workflow

Function

Start

Status

Quality Assurance

Coil Check Body_18

18-Jan-2019, 21:03:46

Success

Quality Assurance

Coil Check Body_18

14-Jan-2019, 22:51:17

Out of Spec

Quality Assurance

Coil Check HeadNeck_20

12-Jan-2019, 12:39:23

Success

Quality Assurance

Coil Check Prostate_2_F_Sen

12-Jan-2019, 12:36:44

Success

Quality Assurance

Coil Check Prostate_2_F_Sen

12-Jan-2019, 12:31:26

Success

Quality Assurance

Coil Check Prostate_2_F_Sen

12-Jan-2019, 12:15:40

Out of Spec

Quality Assurance

Coil Check Prostate_2_F_Sen

12-Jan-2019, 12:14:06

Aborted

Quality Assurance

Coil Check 15Ch_A1_Breast_F

12-Jan-2019, 12:06:52

Success

Quality Assurance

Coil Check Endorectal

12-Jan-2019, 12:02:54

Success

Quality Assurance

Coil Check TxRx_15Ch_Knee

12-Jan-2019, 11:56:45

Success

Quality Assurance

Coil Check FlexSmall_4

12-Jan-2019, 11:52:35

Success

Quality Assurance

Coil Check FlexSmall_4

12-Jan-2019, 11:48:00

Success

Quality Assurance

Coil Check FlexLarge_4

12-Jan-2019, 11:44:12

Success

Quality Assurance

Coil Check FlexLarge_4

12-Jan-2019, 11:39:22

Success

Quality Assurance

Coil Check HandWrist_16

12-Jan-2019, 11:33:52

Success

Quality Assurance

Coil Check FootAnkle_16

12-Jan-2019, 11:25:03

Success

Quality Assurance

Coil Check ShoulderSmall_16

12-Jan-2019, 11:19:59

Success

Quality Assurance

Coil Check ShoulderLarge_16

12-Jan-2019, 11:14:31

Success

Quality Assurance

Coil Check Body_16

12-Jan-2019, 11:00:57

Success

Quality Assurance

Coil Check Body_16

12-Jan-2019, 10:46:24

Out of Spec

Quality Assurance

Coil Check Body_16

12-Jan-2019, 10:26:43

Out of Spec

Quality Assurance

Coil Check Body_16

12-Jan-2019, 10:04:53

Success

Quality Assurance

Coil Check PA_35_F

12-Jan-2019, 09:34:48

Success

Quality Assurance

Coil Check Spine_32

24-Dec-2018, 09:41:05

Success

Quality Assurance

Coil Check Spine_32

24-Dec-2018, 09:40:35

Success

Quality Assurance

Coil Check Spine_32

24-Dec-2018, 09:36:55

Out of Spec

Quality Assurance

Coil Check Spine_32

24-Dec-2018, 09:34:31

Out of Spec

Quality Assurance

Coil Check Spine_32

24-Dec-2018, 09:07:31

Success

Quality Assurance

Coil Check Spine_32

24-Dec-2018, 09:05:23

Success

Quality Assurance

Coil Check Spine_32

24-Dec-2018, 09:05:22

Success

Quality Assurance

Coil Check Spine_32

24-Dec-2018, 08:50:15

Success

Quality Assurance

Coil Check Spine_32

24-Dec-2018, 08:50:03

Success

Quality Assurance

Coil Check Spine_32

24-Dec-2018, 08:45:58

Success

Phantom Shim Check

24-Dec-2018, 08:45:58

Success

Gradient Sensitivity Check

24-Dec-2018, 08:45:58

Success

Gradient Sensitivity Check

24-Dec-2018, 08:45:58

Success

Long Term Stability Check

24-Dec-2018, 08:45:58

Success

Synthesizer Check

24-Dec-2018, 08:45:58

Success

Stability Check

24-Dec-2018, 08:45:58

Success

RF Noise Check

24-Dec-2018, 08:45:58

Success

Spike Check

24-Dec-2018, 08:45:58

Success

Gradient Rise Time Check

24-Dec-2018, 08:45:58

Success

Show as PDF | Update

Service Key Expiry Date: 24-Dec-2019

Details

QA Step

FID check result

Parameter	Value	Min	Unit
FID Maximum Amplitude	15566		ADC
FID Decay Time	9.04	2.00	ms

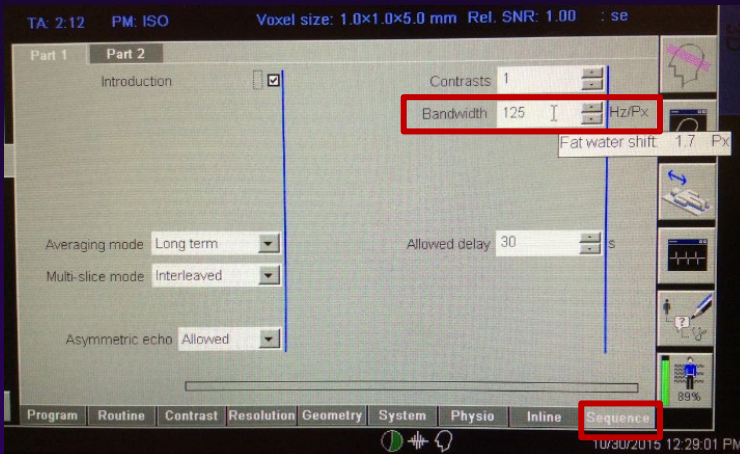
Average

Field Terms

Field Term	Value	Min	Max	Unit
Bpp	1.600	0.000	3.000	ppm
Brms	0.090	0.000	0.400	ppm
A10	-0.011	-0.700	0.700	ppm
A11	-0.044	-0.700	0.700	ppm
B11	0.047	-0.700	0.700	ppm
A20	0.080	-0.700	0.700	ppm
A21	0.039	-0.700	0.700	ppm
B21	0.073	-0.700	0.700	ppm
A22	0.044	-0.700	0.700	ppm
B22	0.019	-0.700	0.700	ppm
A30	-1.008			ppm
A31	-0.575			ppm
B31	0.615			ppm
A32	0.238			ppm
B32	0.450			ppm
A33	-0.495			ppm
B33	0.367			ppm
A40	-0.582			ppm

Siemens: Other options

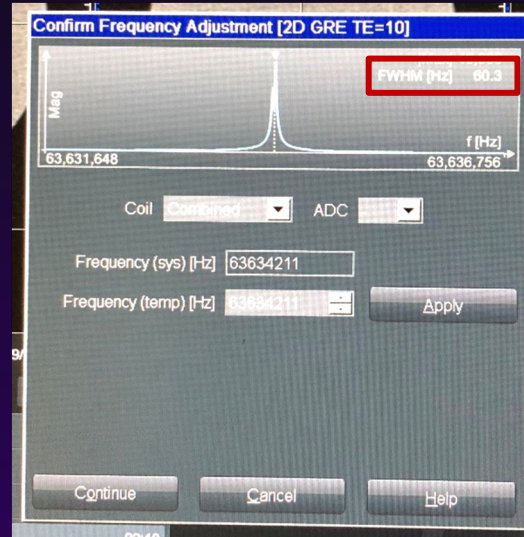
BW difference is generally accessible



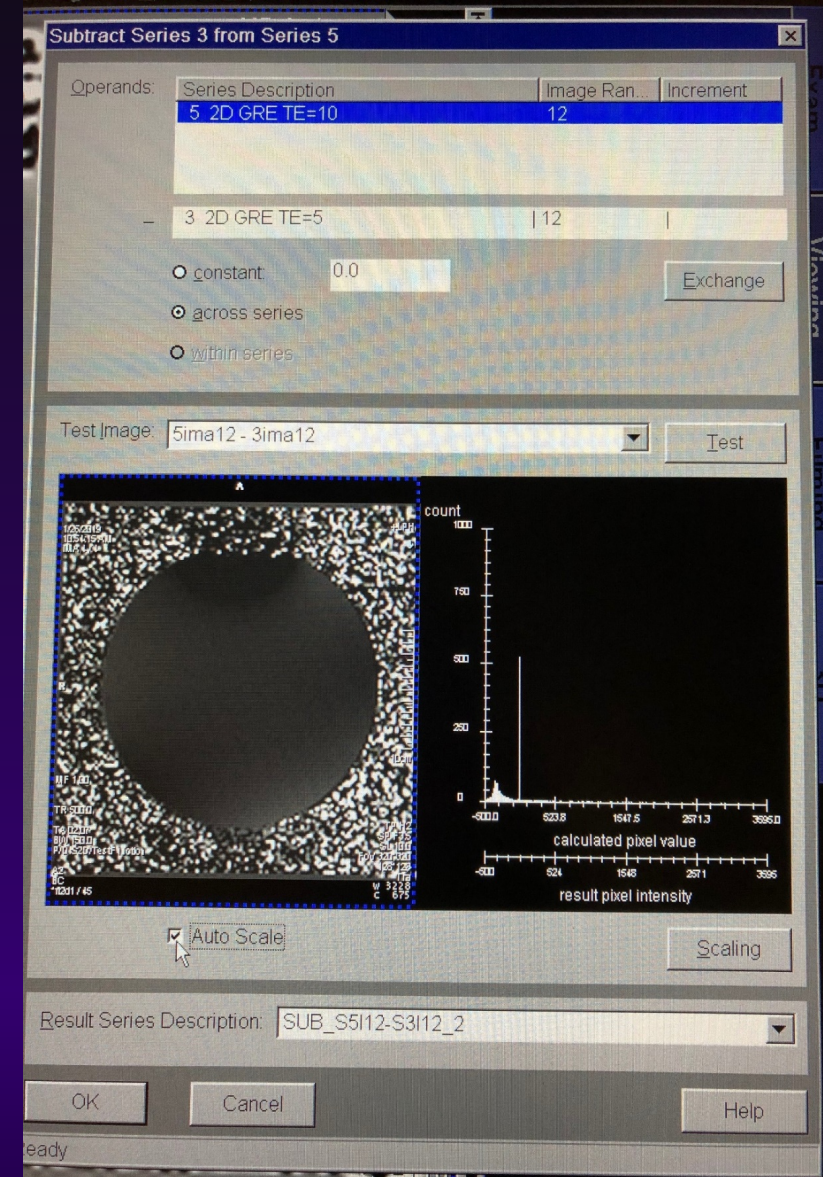
$$\Delta B_o \text{ (ppm)} = \frac{BW_1 \times BW_2 \times (x_1 - x_2)}{\gamma \times B_0 \times FOV \times (BW_2 - BW_1)}$$

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

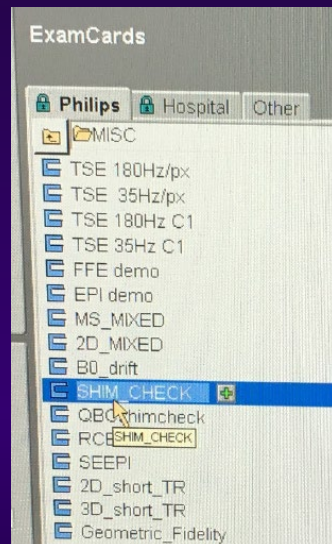


Philips: Shim check procedure

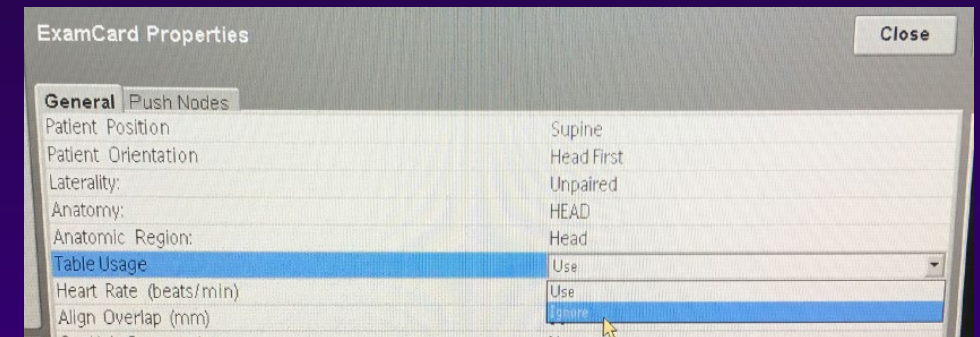
- Accessible field map function: Shim check
- Phantom: 40 cm disk
- Coil: Body



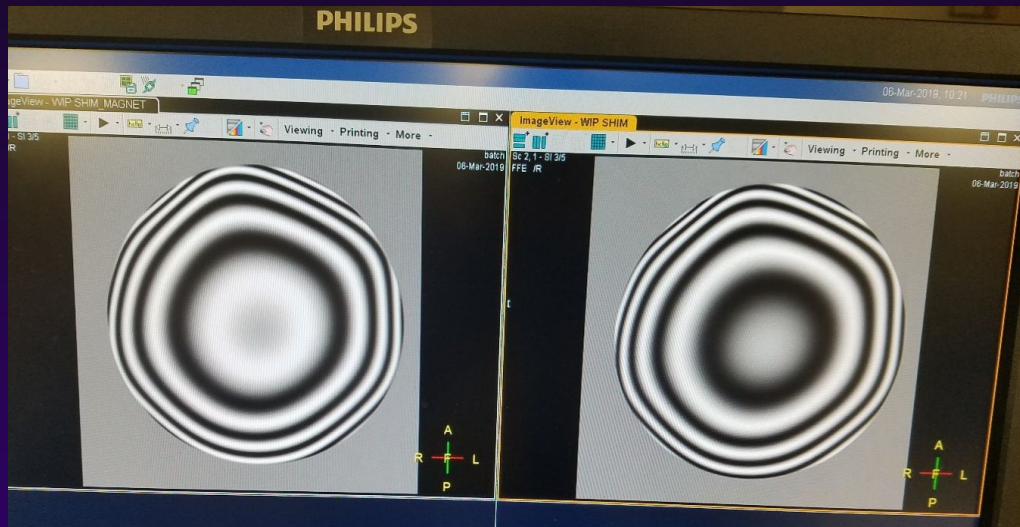
Phantom studies → MISC



Run as is. Example 1.5T parameters below	
Sequence	FFE
TR	400 ms
TE	16 ms
FA	30°
FOV	45 cm



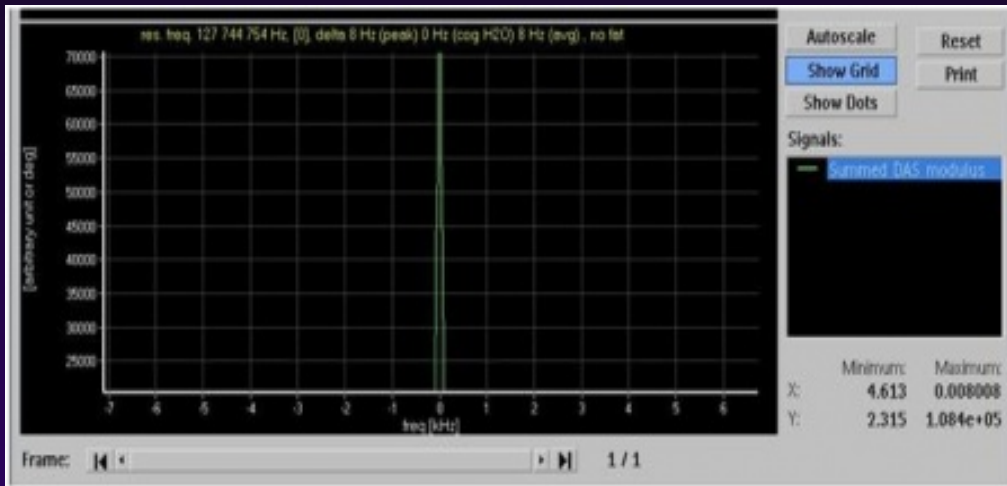
Philips: Shim check results



- Each B→W transition is 1.0ppm. (1 full cycle is 1.0 ppm)
- Count number N of B→W transitions, $\Delta B_{0,pp} = N \times 1.0ppm$
- Re-position phantom and run in 3 planes

Philips: Other options

Spectral peak



After running non-survey scan
Examination→Data Monitoring→
F0→Show Latest
Zoom in on half of Y Maximum to estimate FWHM

BW difference

- Older systems display fat-water shift in pixels instead of bandwidth/pixel
- Calculate Hz/pixel:

$$\frac{\text{Hz}}{\text{pixel}} = \frac{3.5\text{ppm} \times \gamma \left(\frac{\text{MHz}}{T} \right) \times B_0(T)}{\text{fat} - \text{water shift (pix)}}$$

Phase difference map

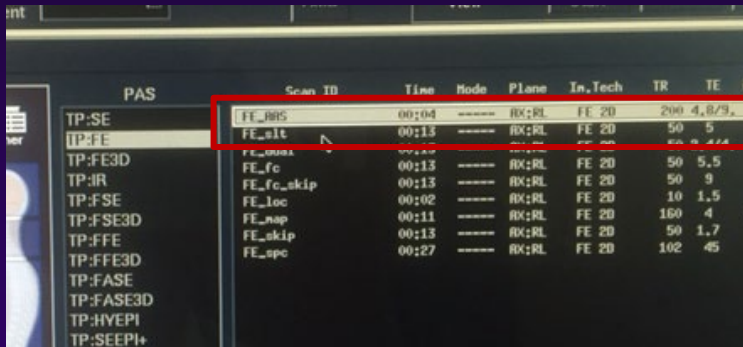
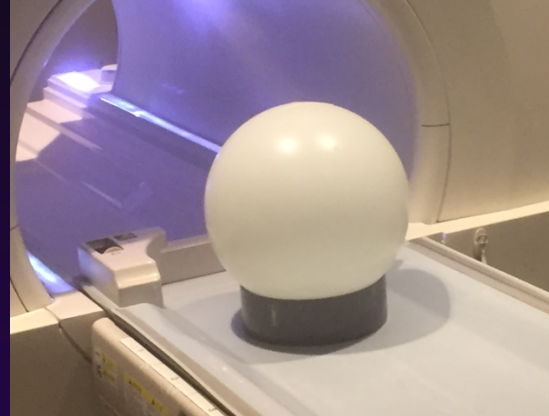
- Phase images can be reconstructed also by selecting M (magnitude) and P (phase) on Postproc→Images on the exam card.
- Use image algebra in viewing environment to subtract
- If necessary, reduce TE difference to reduce phase wraps

Field mapping

- SPT tools can be used with a service dongle

Toshiba/Canon: Phase difference procedure

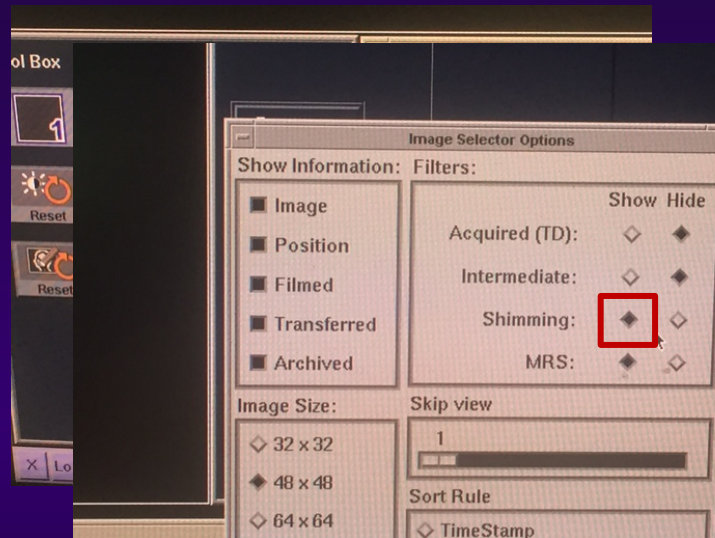
- Phantom: 30 cm spherical
- Coil: Body
- Protocol: FE_AAS



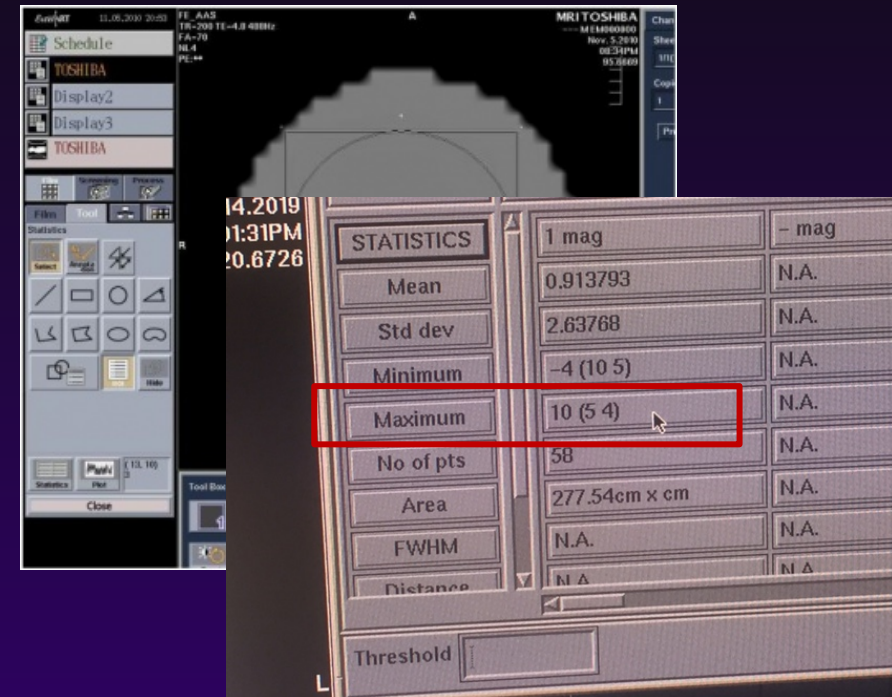
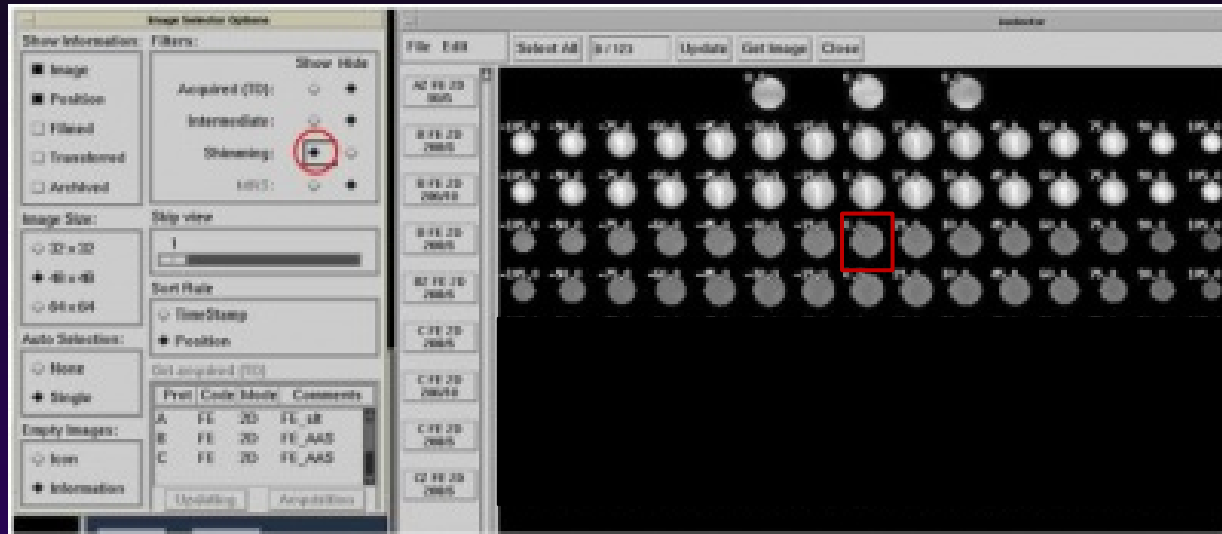
	PAS	Scan ID	Time	Mode	Plane	In.Tech	TR	TE
TP:SE		FE_RIS	00:04	----	RX:RL	FE 2D	200	4.5/9.5
TP:FE		FE_slt	00:13	----	RX:RL	FE 2D	50	3
TP:FE3D		FE_fc	00:13	----	RX:RL	FE 2D	50	5.5
TP:IR		FE_fc_skip	00:13	----	RX:RL	FE 2D	50	9
TP:FSE		FE_loc	00:02	----	RX:RL	FE 2D	10	1.5
TP:FSE3D		FE_map	00:11	----	RX:RL	FE 2D	160	4
TP:FFE		FE_skip	00:13	----	RX:RL	FE 2D	50	1.7
TP:FFE3D		FE_spc	00:27	----	RX:RL	FE 2D	102	45
TP:FASE								
TP:FASE3D								
TP:HVEPI								
TP:SEPI+								

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

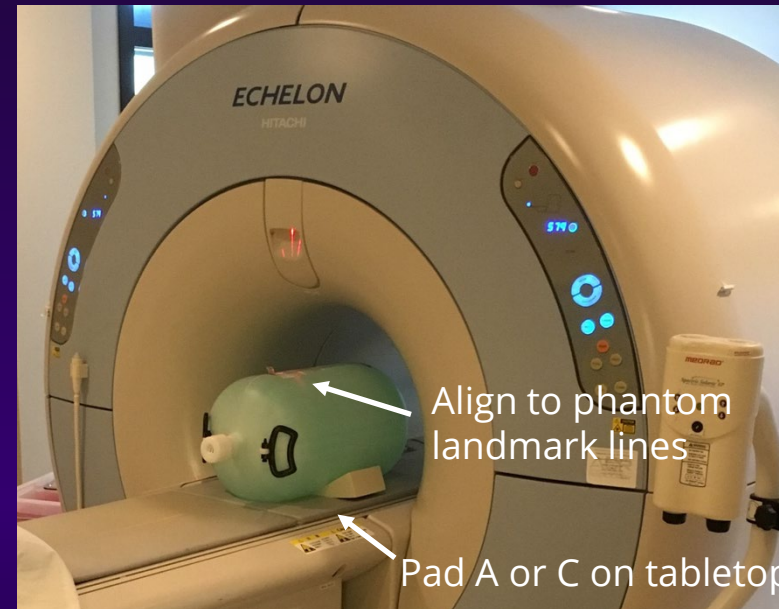
- Oasis & Echelon
- Phantom: Bottle 11
- Coil: RAPID body (Oasis) or T/R Body (Echelon)
- Protocol: Fine magnetic field analysis tool



Oasis

RAPID body coil, laterally centered, no pads (required for valid results)

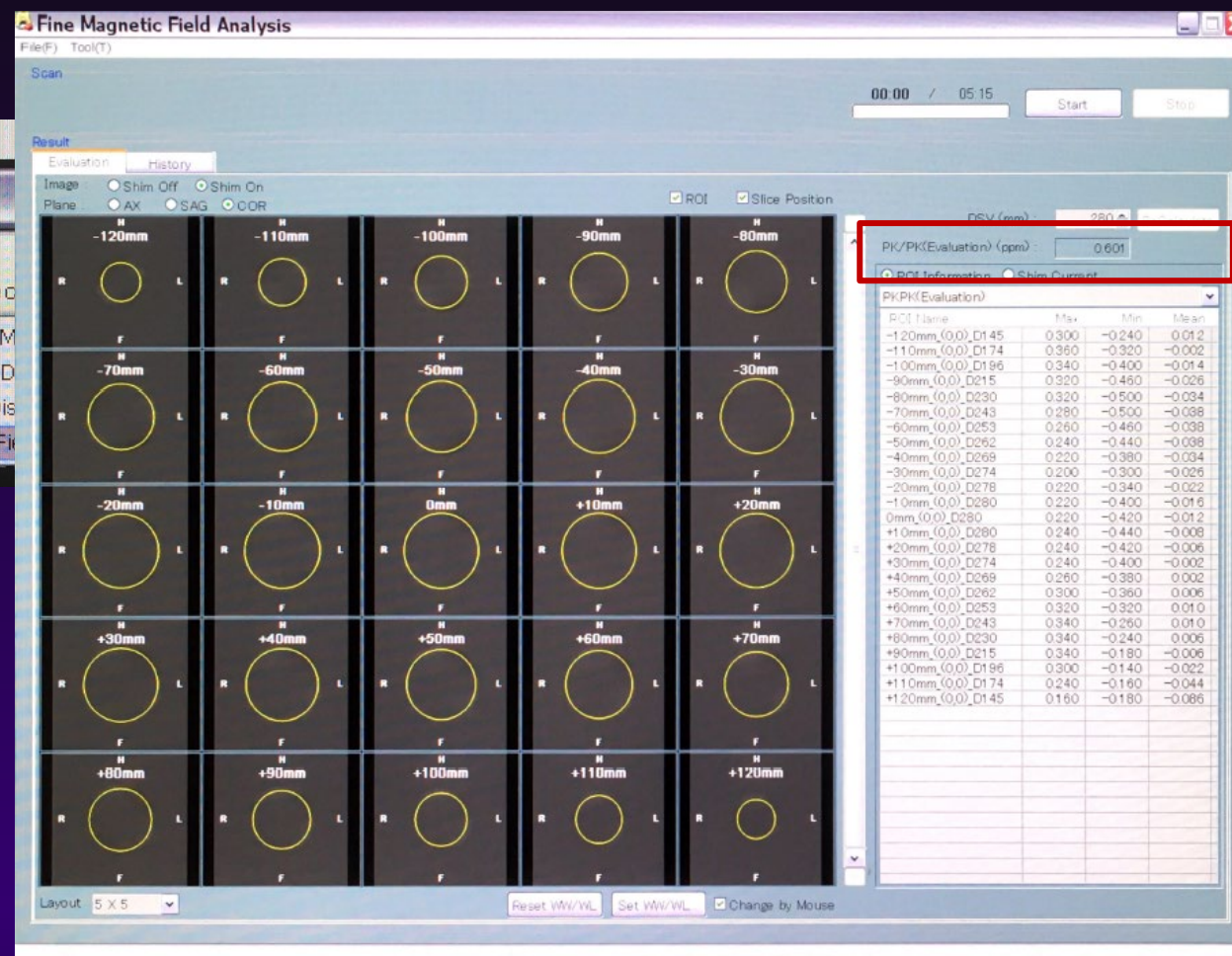
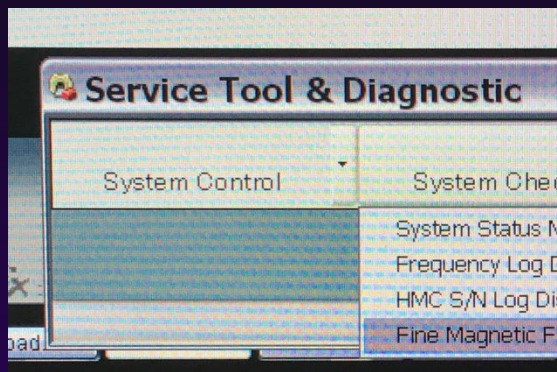
Align laser with phantom landmarks, not coil



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

Axial: TR= 1850, Multi Slice=15, Presat=0, W=11, L=500, Prescan=ON
Sagittal: TR= 2430, Multi Slice=15, Presat=4, W=11, L=500, Prescan=ON
Coronal: TR= 2430, Multi Slice=15, Presat=4, W=11, L=500, Prescan=ON

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

Slice Number	Slice position (mm)	ROI diameter (mm)
1	-70	110
2	-60	134
3	-50	150
4	-40	160
5	-30	170
6	-20	175
7	-10	178
8	0	180
9	10	178
10	20	175
11	30	170
12	40	160
13	50	150
14	60	134
15	70	110

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

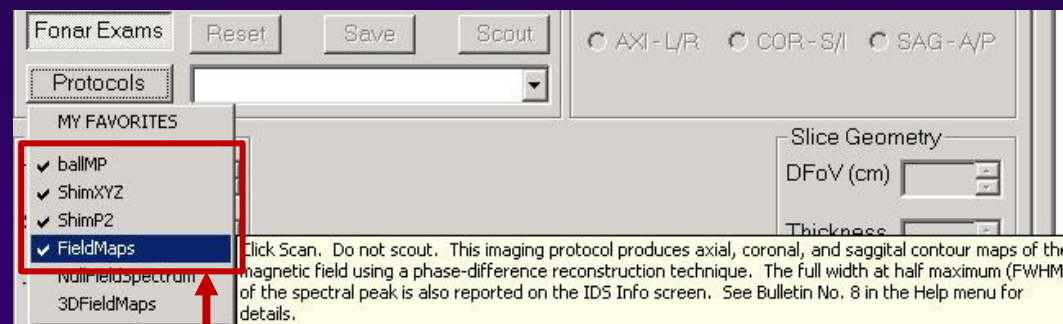
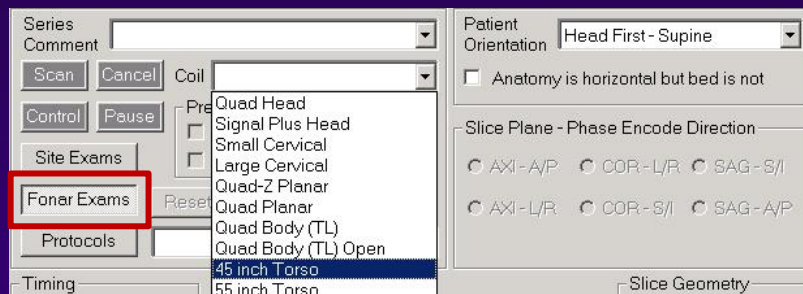
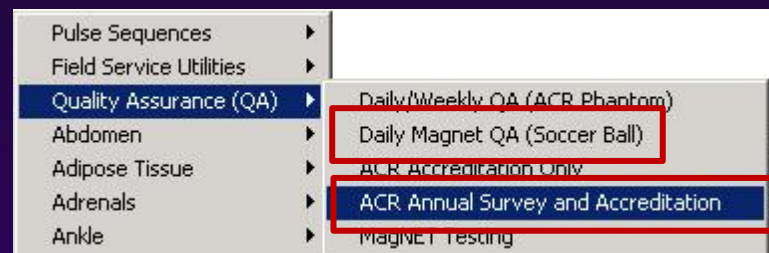
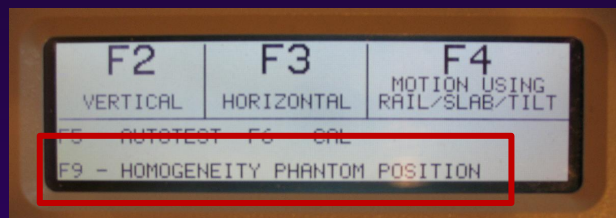
Airis 2: $\Delta B_0 = 0.114 \text{ ppm} * \text{Max(Rel.)} - \text{Min(Rel.)}$
Airis Elite: $\Delta B_0 = 0.104 \text{ ppm} * \text{Max(Rel.)} - \text{Min(Rel.)}$
Altaire: $\Delta B_0 = 0.068 \text{ ppm} * \text{Max(Rel.)} - \text{Min(Rel.)}$

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

Airis 2: $\Delta B_0 \leq 1.5 \text{ ppm}$
Airis Elite: $\Delta B_0 \leq 1.5 \text{ ppm}$
Altaire: $\Delta B_0 \leq 1.75 \text{ ppm}$

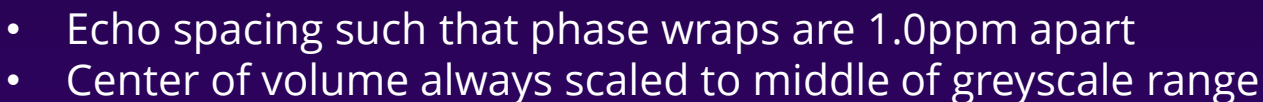
Fonar: Field map procedure

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



Run these in order

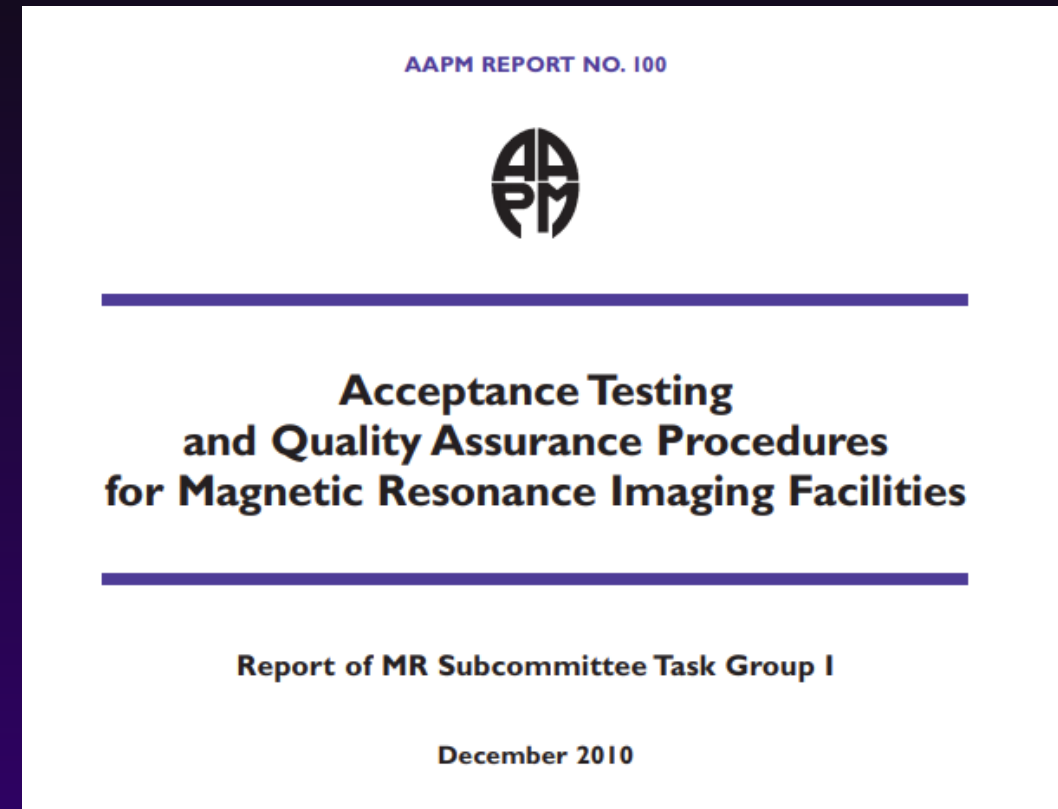
© 2004 Blackwell Publishing Ltd *Journal of Internal Medicine* 255: 105–112



OVERVIEW

More Resources: AAPM Report 100

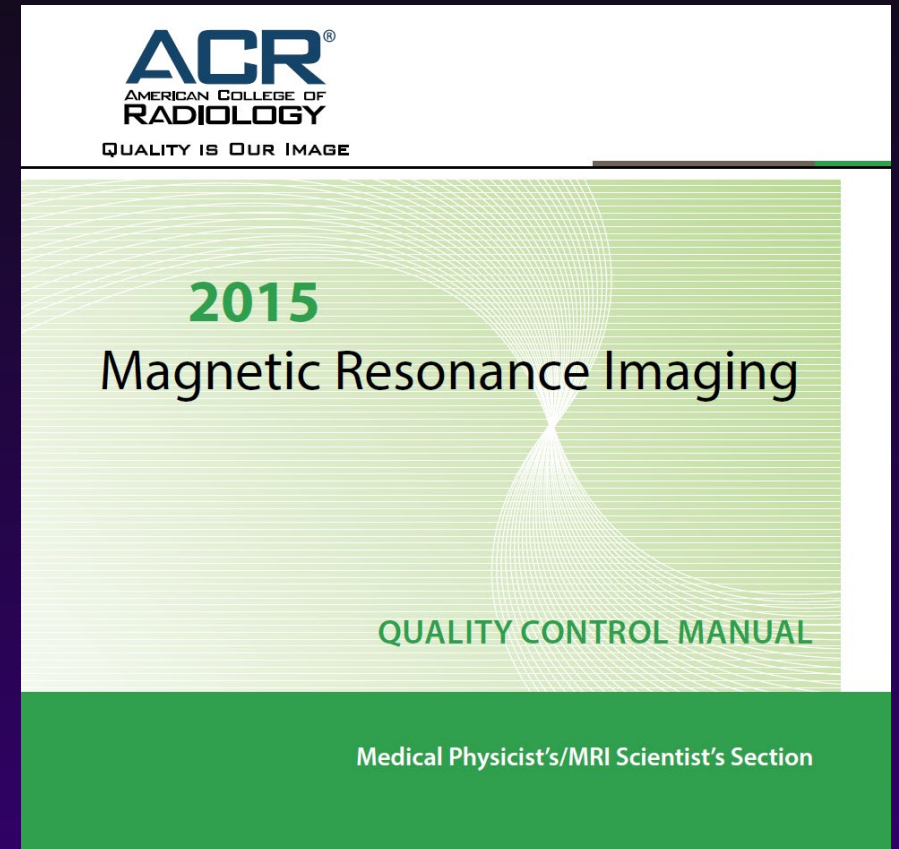
- Details sources and impacts of poor homogeneity
- Overview of 3 measurement methods
- Advantages and disadvantages of each
- Suggested acceptance criteria for routine and ultrafast imaging



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



https://www.acr.org/-/media/ACR/NOINDEX/QC-Manuals/MR_QCManual.pdf

More Resources

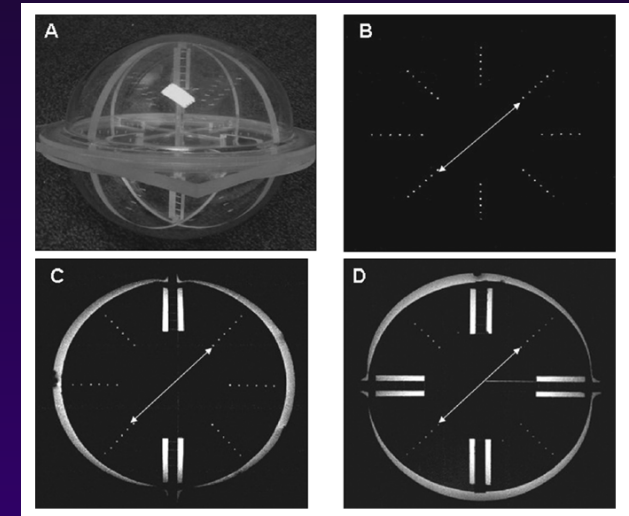
- **Bandwidth difference method:** Chen HH, Boykin RD, Clarke GD, Gao JHT, Roby JW. Routine testing of magnetic field homogeneity on clinical MRI systems. *Med Phys* 2006 33(11)

Routine testing of magnetic field homogeneity on clinical MRI systems

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(Received 28 March 2006; revised 21 July 2006; accepted for publication 11 September 2006;
published 23 October 2006)



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