Physicists' Quality Control for MR Equipment

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Overview

- ABR and the role of the Qualified Medical Physicist/ MR Scientist
- Phantom selection and the degree of latitude given the QMP/MRS
- Annual survey tests:
  - Magnetic field homogeneity
  - RF Coil SNR, image uniformity & ghosting
- Roles of physics assistants & technologists

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ACR MRI Accreditation Program Overview

- Evaluates effectiveness of quality control measures
- Collects findings to further the development of quality control information
- Promotes the Qualified Medical Physicist / MRI Scientist as individual responsible for overseeing the equipment quality control program

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ACR Position on QMP/MRS

- Starting July 1, 2005, sites applying for MRI accreditation must submit an annual MRI system performance evaluation performed by a medical physicist or MR scientist.
- The medical physicist/MR Scientist will follow the ACR MRI Quality Control Manual in order to perform a complete annual system performance evaluation.

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ACR Position on QMP/MRS

- This evaluation includes an evaluation of the weekly QC performed by a technologist.
- A technologist may still perform the ACR phantom portion of the accreditation submission
  - the ACR strongly recommends the services of a medical physicist or MR scientist for this also.

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Qualified Medical Physicist or MR Scientist ?

Qualified Medical Physicist : ACR recommends that the individual be certified in the appropriate subfields* by:

- the American Board of Radiology
- the Canadian College of Physics in Medicine, or
- for MRI, by the American Board of Medical Physics in MRI physics

*The appropriate subfields of medical physics for this standard are Diagnostic Radiological Physics and Radiological Physics.

ACR Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) equipment (amended 2006)

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Qualified Medical Physicist or MR Scientist ?

Qualified MRI Scientist –

- obtained graduate degree in a physical science involving nuclear MR or MRI
- Should have 3 yrs. of documented experience in a clinical MRI environment.

- Physicist/MR scientist *shall be knowledgeable in*:
  - principles of MR safety, FDA & other regulations
  - Nuclear physics & MRI technology
  - clinical imaging protocols and their methods of optimization

ACR Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) equipment (amended 2006)

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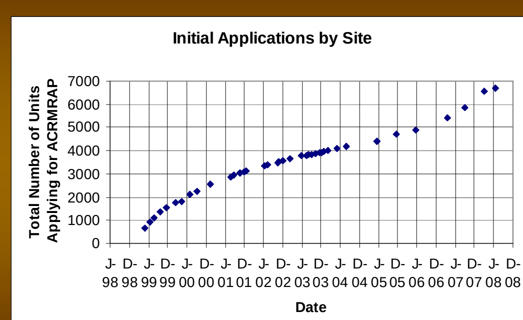
Initial MRAP Applications



Estimate of initial applications based on numbers of units submitting MRAP phantom studies for review

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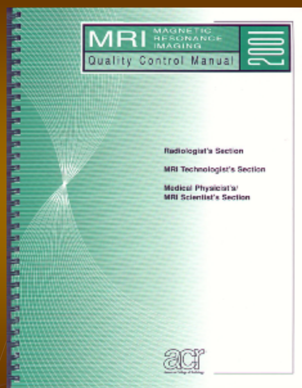
ACR Magnetic Resonance Imaging Quality Control Manual *(rev. 2004)*



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MRI Accreditation Standard Phantom Design Goals

- Easy to Use
  - Multiple inserts
  - Not too bulky
  - Applicable to all MRI systems
- Moderately Priced
  - $1050

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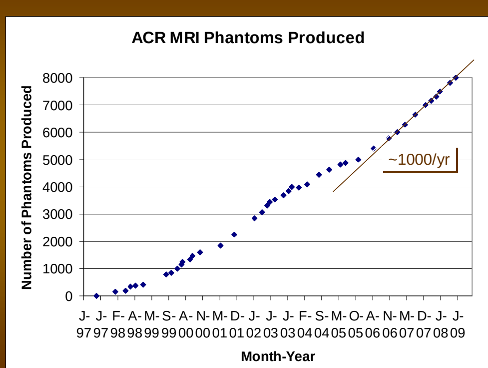
ACR Standard MRI Phantoms



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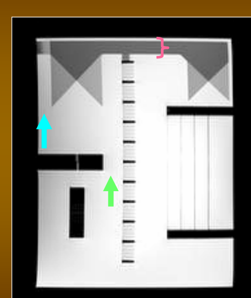
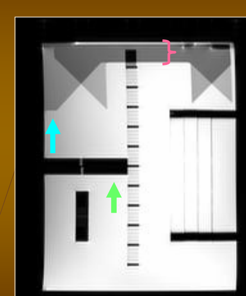
MRAP Standard Phantom Models



S/N 2256



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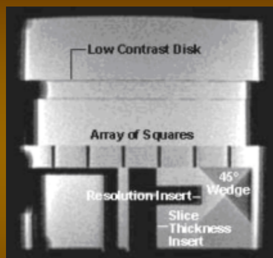
ACR MRAP Small Phantom



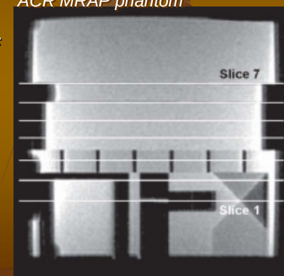
Small version of standard ACR MRAP phantom – designed for use is clinics that have dedicated extremity imagers that allow application for ACR Accreditation of knee module only.

Phantom Test Guidance for Use of the Small MRI Phantom for the ACR MRAP

MRAP Small Phantom Specs

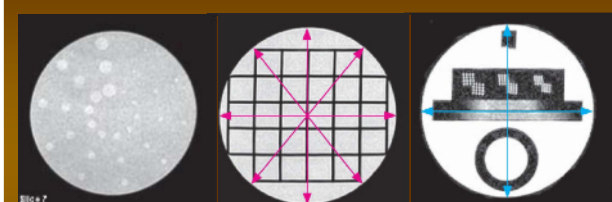
- inside length 100 mm
- inside diam. 100 mm
- filled with a solution of NiCl & NaCl
  - 10 mM NiCl2 and 0.45% by weight aqueous NaCl.
- A separate vial is filled with 20 mM NiCl2 but no aqueous NaCl.

Saggital image show positions for seven slices acquired with small ACR MRAP phantom



Phantom Test Guidance for Use of the Small MRI Phantom for the ACR MRAP

MRAP Small Phantom Specs



- *Slices are nominally 5mm with 3 mm gaps*
- *12 cm FOV; matrix size is nominally 192 (fe) × 152 (pe)*
- *High contrast resolution arrays are 0.9mm, 0.8mm & 0.7mm*
- *Crossed wedges have 45º slopes - the bar length difference is twice the actual slice displacement error*

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MRI Phantoms: General Features

– Nonsignal-producing container

– Proton density similar to water

– Shorten T1: NiCl & $CuSO_4$

– Mimic Conductivity of tissues: NaCl

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Phantoms Developed by Users

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Responsibilities of the Medical Physicist / MRI Scientist

- Write Purchase Specifications
- Perform Acceptance Testing
  - Baseline Measurements
- Determine Action Limits
- Set up Daily/Weekly QC Tests
- MRI equipment performance review

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MRI Annual Performance Review

- Should be performed by a qualified medical physicist or MRI scientist
- Should be done <u>at least</u> once a year
  - Also after major hardware repair and/or upgrades

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Annual Survey Tests

- Magnetic Field Homogeneity
- Slice Position Accuracy
- Slice Thickness Accuracy
- Radio Frequency Coil Checks
- ~~Inter-Slice RF Interference~~
- ~~Soft Copy Displays (monitors)~~

See ACR MRI QC Manual

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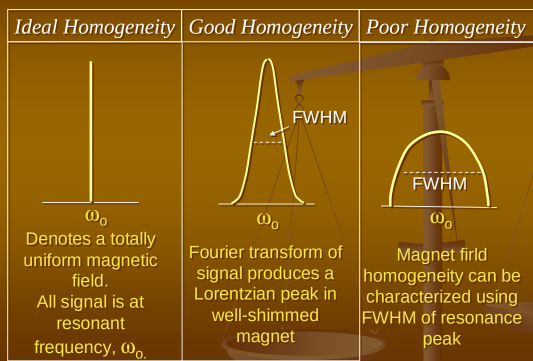
Magnetic Field Homogeneity



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Is it required to perform the homogeneity test for the annual system performance evaluation?

- Yes, a homogeneity test of some kind is required as part of the annual system performance evaluation for **all** accredited magnets, and those applying for accreditation.
- The ACR QC Manual describes this in the Medical Physicist's/MR Scientist's section.

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Is it required to perform the homogeneity test for the annual system performance evaluation?

- If the methods in the QC Manual can't be performed, a field map or equivalent field homogeneity assessment that has been performed within the last 12 months from the service engineer may be submitted.
- The QMP/MRS may use alternate method of accurately assessing homogeneity but must include a description of the methodology.

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Is it required to perform the homogeneity test for the annual system performance evaluation?

- A potential alternate method that may be used with systems that do not provide access to either phase-angle images or spectroscopy is the "Bandwidth-difference" method.

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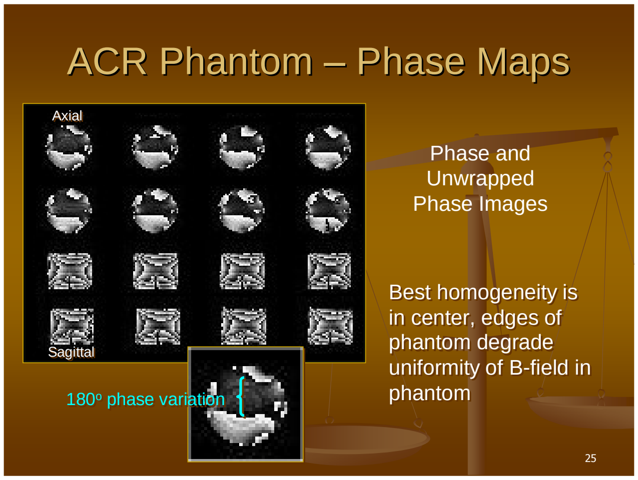
ACR Phantom – Phase Maps
Axial
Sagittal
Phase and
Unwrapped
Phase Images
Best homogeneity is
in center, edges of
phantom degrade
uniformity of B-field in
phantom
180º phase variation
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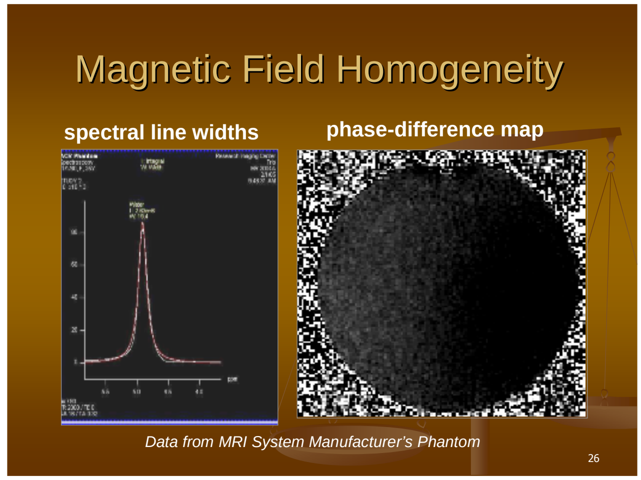
Magnetic Field Homogeneity
spectral line widths
phase-difference map
Data from MRI System Manufacturer's Phantom
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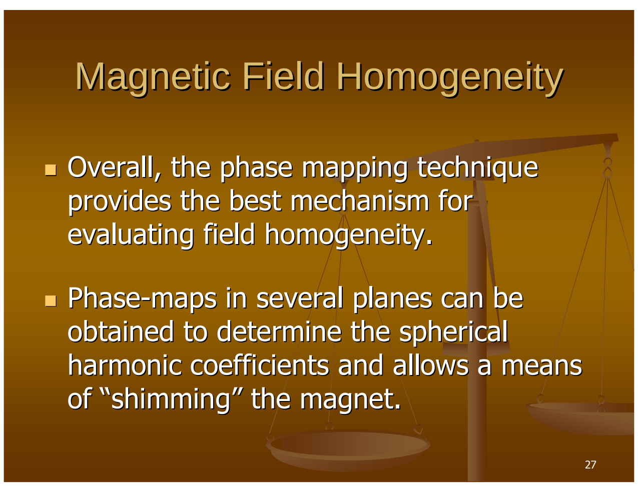
Magnetic Field Homogeneity
Overall, the phase mapping technique provides the best mechanism for evaluating field homogeneity.
Phase-maps in several planes can be obtained to determine the spherical harmonic coefficients and allows a means of "shimming" the magnet.
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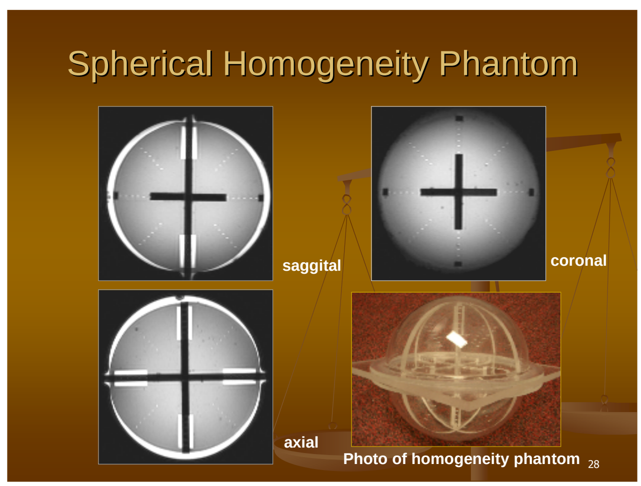
Spherical Homogeneity Phantom
saggital
coronal
axial
Photo of homogeneity phantom
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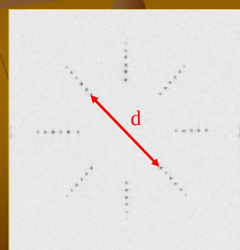
Bandwidth-Difference Method

$$MFH(x,y) = \frac{BW_1 \cdot BW_2(d_1 - d_2)}{\bar{\gamma} \cdot FOV \cdot (BW_2 - BW_1)}$$

- The MFH is measured from the change in distance between landmarks in the phantoms between the two bandwidths.
- FOV = field of view in m
- $\bar{\gamma} = \gamma/2\pi$ = 42,567 Hz/mT



Chen HH et al. Medical Physics, 2006, 33(11): 4299-4306.

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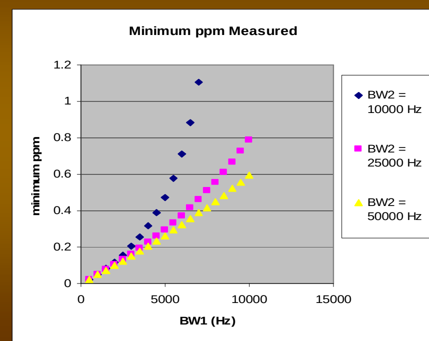
Optimization of Parameters



FOV = 330 mm

d_1-d_2 = 1 mm

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Magnetic Field Homogeneity

- For some systems, service personnel may provide use of phase-mapping acquisition and analysis tools.
- Filmed copy of vendor's final homogeneity map and shim coefficients is useful for documenting initial conditions and establishing a baseline.

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Radio Frequency Coil Checks

- Volume coils
- Signal-to-noise ratio
- Percent integral uniformity
- Percent signal ghosting
- Surface Coils Maximum SNR Tests

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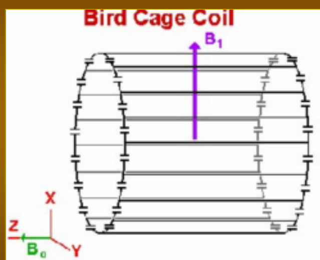
Bird-Cage Head Coil



RF coils produce uniformity patterns characteristic of their design.

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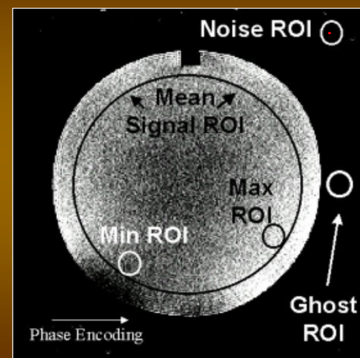
Volume RF Coil Measurements



ACR Phantom Slice #7

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Image Intensity Uniformity

- Performance criteria: PIU ≥ 87.5%
  except 3T (82%)

$$\text{percent integral uniformity} = 100 \times \left(1 - \frac{(high - low)}{(high + low)}\right)$$

- Measurement Considerations:
  - Display may not show signal values
  - Display may not allow user to set signal display level
  - There may not be a well-defined high/low intensity level

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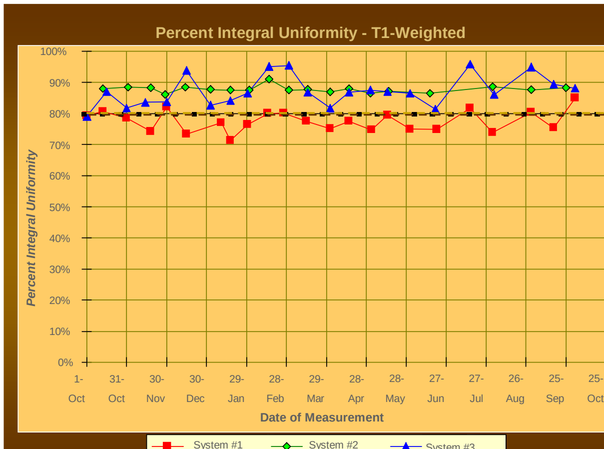

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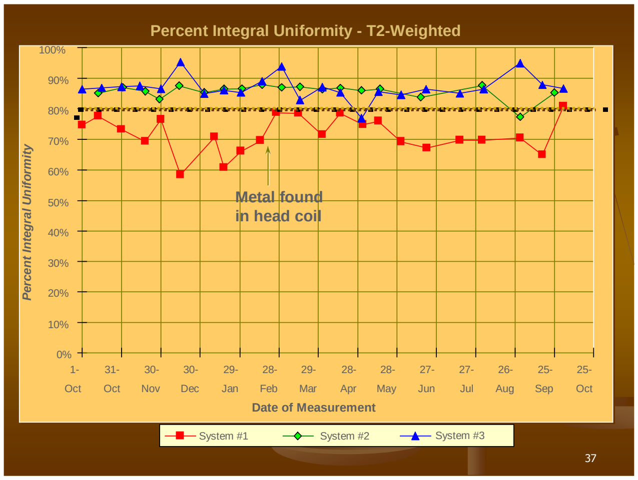
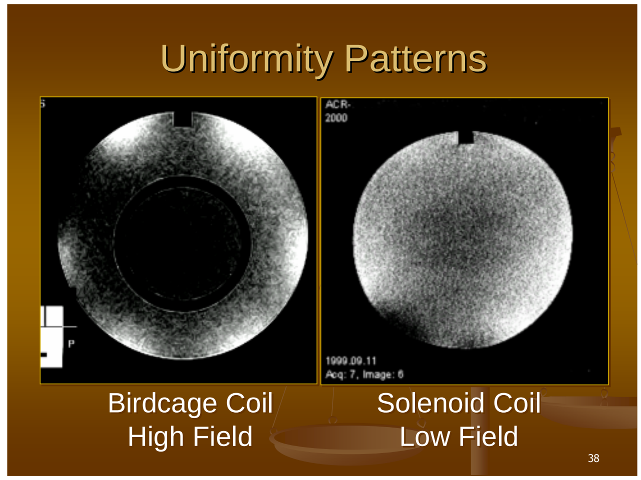

Percent Integral Uniformity - T2-Weighted
Percent Integral Uniformity
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Metal found in head coil
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
27-Jul
26-Aug
25-Sep
25-Oct
Date of Measurement
System #1
System #2
System #3
37


Uniformity Patterns
ACR-2000
1999.09.11
Acq: 7, Image: 6
Birdcage Coil
High Field
Solenoid Coil
Low Field
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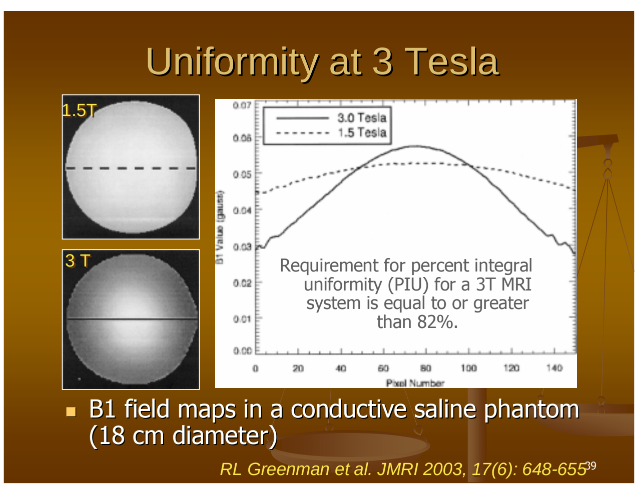
Uniformity at 3 Tesla
1.5T
3 T
3.0 Tesla
1.5 Tesla
B1 Value (gauss)
Pixel Number
Requirement for percent integral uniformity (PIU) for a 3T MRI system is equal to or greater than 82%.
B1 field maps in a conductive saline phantom (18 cm diameter)
RL Greenman et al. JMRI 2003, 17(6): 648-655
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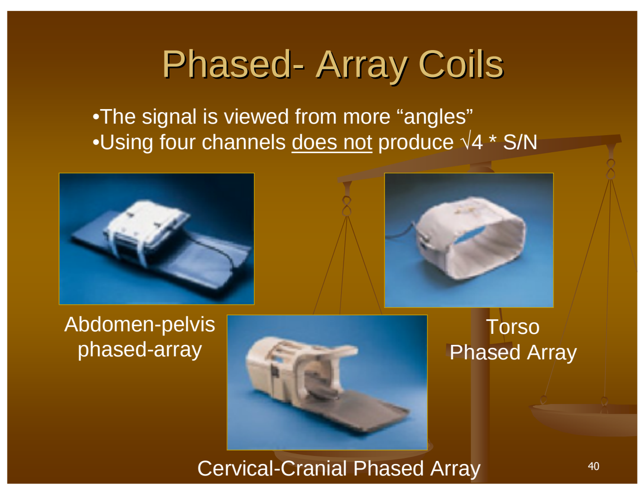
Phased- Array Coils
•The signal is viewed from more "angles"
•Using four channels does not produce √4 * S/N
Abdomen-pelvis phased-array
Torso Phased Array
Cervical-Cranial Phased Array
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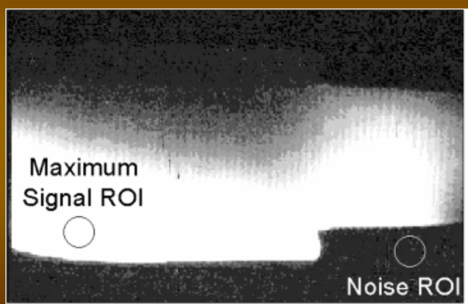
Surface RF Coil Measurements



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Volume Coil Data

% Image Uniformity	Max Signal Min Signal
Signal-to-Noise	Mean Signal SD of Background Signal
Percent Signal Ghosting	Ghost Signal Mean Signal Background Signal

Surface Coil Data

Maximum Signal-to-Noise	Maximum signal SD of Background Signal

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MRI Physics Assistants

- QMP/MRS may be assisted in obtaining QC test data by properly trained individuals.
- These individuals must be trained and approved by the QMP/MRS in the:
  - techniques of performing the tests
  - function and limitations of the imaging equipment and test instruments
  - reasons for the tests
  - importance of the test results.
- The QMP/MRS must review and approve all measurements.

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MRI QC Program Roles

- MRI Physicist
  - runs baseline tests of system performance
  - sets action criteria for routine ACR phantom tests
  - performs annual calibration checks with appropriate phantoms
  - reviews QC program

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MRI QC Program Roles

- Technologist
  - performs daily tests to assess image quality using ACR phantom
  - Weekly checks of hard copy output
- All measurements made, problems discovered, and actions required to resolve the problems are recorded for review

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Summary

- As of June 2009, ACR's MRAP has about 7000 participating sites
- The qualified medical physicist/MRI scientist plays an important role in the QC aspects of the MRAP
- The ACR phantom is not adequate for all QC test – the QMP/MRS must use other phantoms & methods
- MRI magnet homogeneity is an important but problematic test

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Summary

- All radiofrequency coils must be tested in every mode of operation used clinically
- This may pose a challenge for newer, many-channel systems
- It is advisable to use coil manufacturer's phantoms and tests where available
- ACR has posted all Testing & QC Forms for download at: http://www.acr.org/accreditation/mri/mri_qc_forms.aspx

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