Troubleshooting the ACR MRI Accreditation Phantom Data

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Documents from ACR

- Site Scanning Instructions
  - Positioning & scan parameters
- Phantom Test Guidance for the ACR MRI Accreditation Program
  - Analysis of Images - measurements
- ACR MRI Quality Control Manual
  - Describes the use of MRI image quality data for equipment quality control

Method of Review

- What are the "normal" range of values expected?
- What "normal" artifacts may effect image analysis?
- What are the most likely sources of error?
  - Scanning errors
  - Interpretation errors
  - Equipment errors

Artifacts

- Should be recognized for three different situations:
  1. Artifact is present but not important to the analysis of scanner performance
  2. Artifact is present and is used as a tool for analyzing scanner performance
  3. Artifact is present and by its presence indicates a deficiency in scanner performance
- Same type of artifact may have different role for various sections of phantom

Type I Artifacts

Artifact is present but not important to the analysis of scanner performance

Fourier Truncation Artifact

Fourier Convolution Theorem:

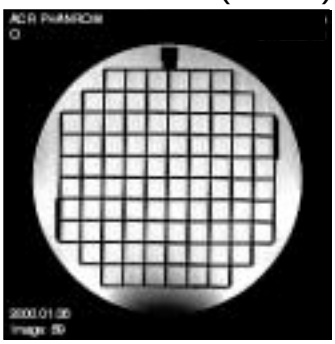
$$\rho_{DFT} = \int_{-L_x/2}^{L_x/2} \bar{\rho}(\tau) h(x-\tau) d\tau = \int_{-\infty}^{\infty} \rho(t) h(x-\tau) d\tau$$

or $\rho_{DFT} = \rho(x) * h(x)$

The convolution kernel, h(x), is oscillatory and merges closely spaced features together gives rise to spurious ringing

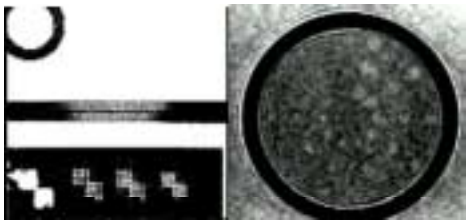
This effect is most pronounced where the image exhibits a step discontinuity of signal intensity

Truncation (Gibbs) Artifact



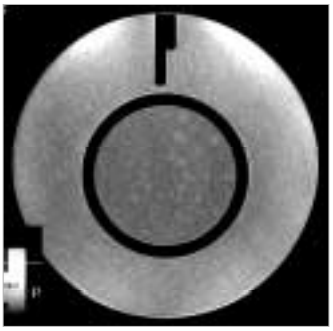
- Appears as lines of alternating darkness and brightness
- Occurs in both read-out and phase-encoding directions

Gibbs Artifacts



- Most problematic in slice select and low contrast detectability inserts

Excessive Truncation Artifacts



If receiver bandwidth is set too low, images become susceptible to major truncation artifacts.

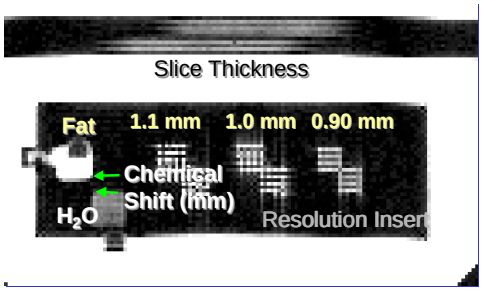
Methods for Reducing Truncation (Gibbs) Artifacts

- Use smoothing filter
  - Will cause high contrast spatial resolution to be degraded
- Use large matrix size
- Don't have regions with abrupt signal intensity transitions in the phantom

Type II Artifacts

Artifact is present and is used as a tool for analyzing scanner performance

ACR MRI Phantom Chemical Shift Insert



Estimating Receiver Bandwidth

Distance between Fat & Water represents the amount of the field of view which spans 3.5 ppm of the resonant frequency.

$$\text{Bandwidth (Hz)} = \frac{\text{FOV(mm)} \times (3.5 \times 10^{-6}) \times \text{proton frequency(Hz)}}{\text{chemicalshift(mm)}}$$

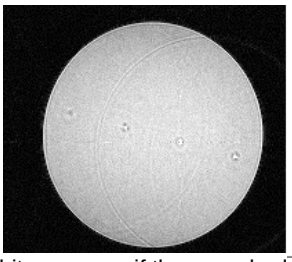
Type III Artifacts

Artifact is present and by its presence indicates a deficiency in scanner performance

Errors in Data

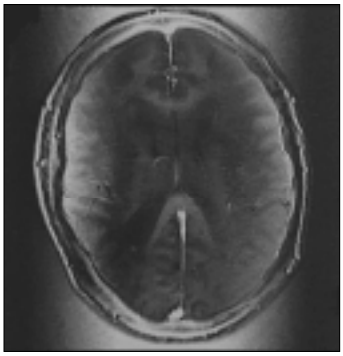
- Signal Digitization Errors
- Saturation of ADC
- Discrete RF Noise
- Synchronous RF Noise

Signal Digitization Errors

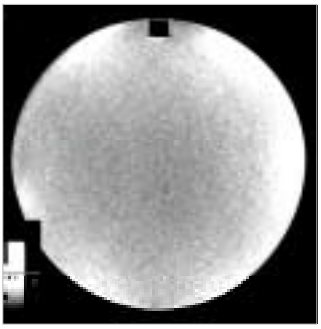


Stuck bit can occur if there are bad memory locations or bad connectors in the parallel data bus

Saturation of ADC

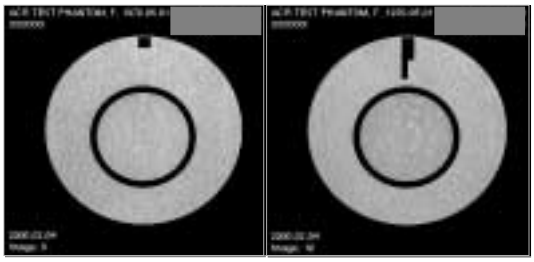


RF Noise/Leaks/ Spikes



Single frequency artifact shows up as zipper in middle of image.

Data Drop Out Artifacts



Slice #8 Slice #10

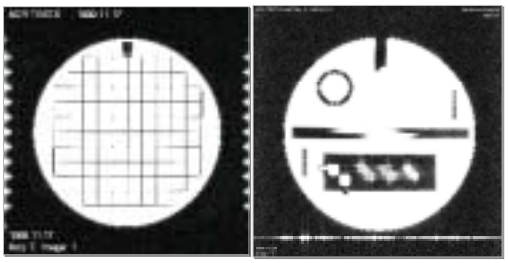
DC-offset Artifacts

- Zero frequency artifacts
- Not important if off to side
- Can be controlled

Small DC Offset

- Phase alternating receiver signal by 180º for successive phase-encoding steps

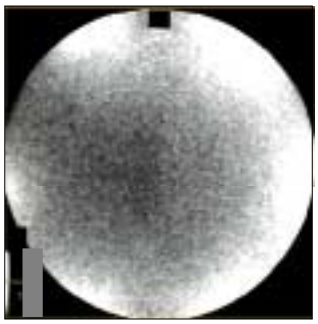
DC Offset Artifact



Large artifact off to side
NSA=1; frequency shifted

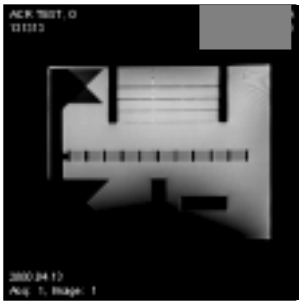
Artifact in Image
May be RF Leak

Zipper Artifact



- Due to transverse magnetization created by 180º refocusing pulse. Can be eliminated with crushers.

Zipper in Sagittal Image

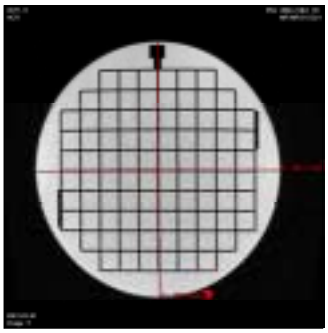


- May be due to large slice thickness
- Inadequate suppression of stimulated echo artifact

Eight Tests

- Geometric Accuracy
- High Contrast Spatial Resolution
- Slice Thickness Accuracy
- Slice Position Accuracy
- Image Intensity Uniformity
- Percent Signal Ghosting
- Low Contrast Detectability

Geometric Accuracy

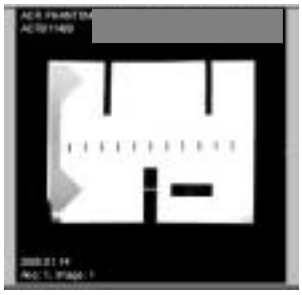


- Measure distance along main axes of phantom
- Compare with known values

Potential Causes of Geometric Accuracy Failures

1. Phantom mispositioning
2. Gradient miscalibration
3. B_0 inhomogeneity
   a. Ferromagnetic objects in magnet
   b. Poor magnet shimming
4. Gradient non-linearity
5. Inappropriate receiver bandwidth
6. Poor eddy current compensation
7. Combination of two or more of above

Localizer – Poor Positioning

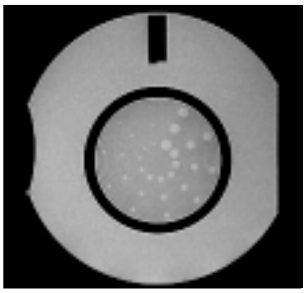


- Only one wedge is present

Gradient Correction

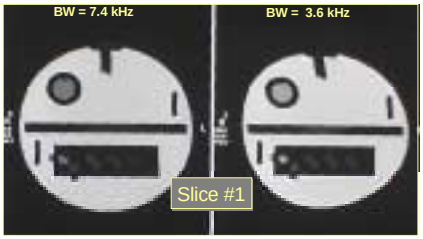
- If gradients are inherently non-linear gradient correction may be applied

Aliasing



- Field of view too small for size of imaged object

Geometric Accuracy - Axial

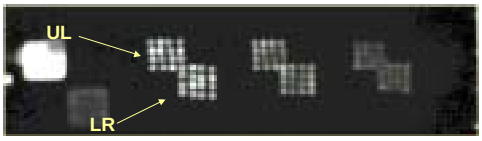


Failure Due To:
- Miscalibrated Gradients
- Low Receiver Bandwidth
- High B_o Inhomogeneities

Air Bubble

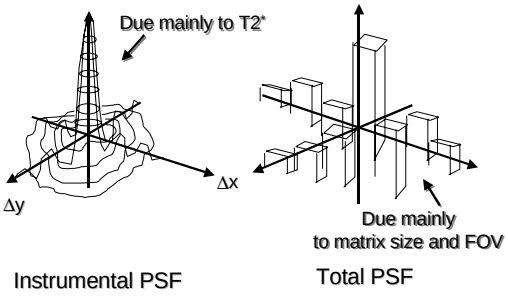
- When air bubble is in phantom, geometric distortion measurement may have to be taken along diagonal

High Contrast Spatial Resolution



- Evaluate conspicuity of holes arranged in two square matricies
- Has to avoid partial-volume artifact…

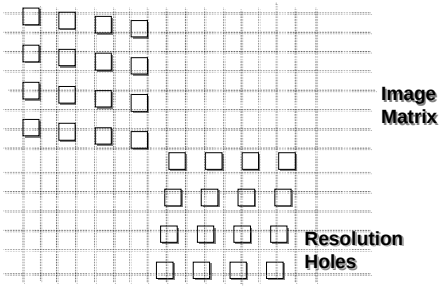
Total Point Spread Function



Instrumental PSF

Total PSF

Spatial Resolution Matrix: Registration with Phantom



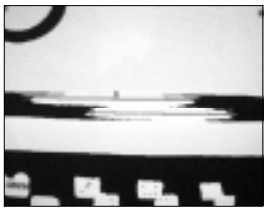
High-Contrast Spatial Resolution

- Causes of failure:
  - Incorrect FOV or matrix
  - Bad gradient calibration
  - Excessive filtering (smoothing)
  - Poor eddy current compensation
  - Gradient amplifier instability

Slice Thickness

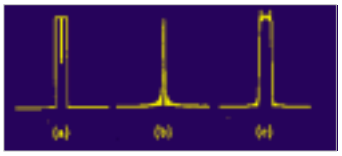
Lower display to one/half the average.

Measure lengths of top and bottom ramps and calculate slice thickness.



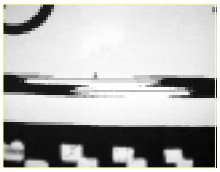
$$\text{Slice Thickness} = 0.2 \times \frac{(\text{top} \times \text{bottom})}{(\text{top} + \text{bottom})}$$

Truncation Errors (Gibbs Artifact)



True image function, ρ(x) | Convolution kernel, h(x) | Fourier reconstruction, $\rho_{DFT}(x)$

Truncation Artifact is prominent in ACR slice thickness insert



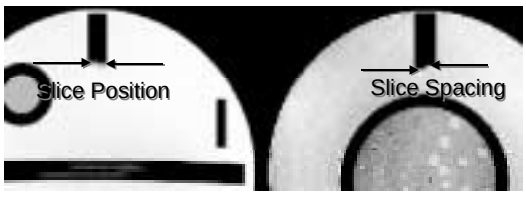
Slice Thickness Actions

- Slice thickness measured should be ± 0.7 mm of prescribed value
  - ± 14% error on 5mm slice
- Corrective actions:
  - Check Axial Site Series Images
  - Replace cables & connectors, look for other sources of distorted RF pulse shape in RF electronics
  - Try switching RF coils
  - Check gradient calibration

Slice Position Accuracy

- Must Pass on ACR T1-weighted and ACR T2-weighted Series ONLY
- Uses Crossed-Wedges as Reference for Positioning and Slice Spacing Accuracy

Slice Position Accuracy



SLICE #1 SLICE #11

Crossed wedges should be of equal length if position and spacing are accurate

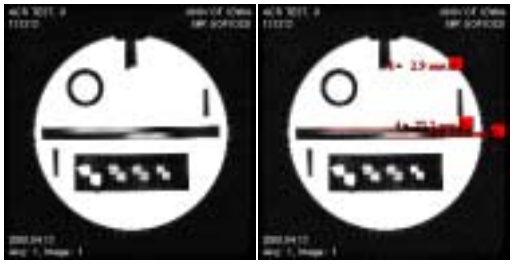
Slice Position Accuracy

- Performance criteria:
  - magnitude of bar length difference ≤ 5 mm.
  - The actual displacement is ½ of the measured difference.
- Measurement Concerns:
  - Operator may strive for more precision than is necessary

Slice Position Accuracy

- Causes of failure:
  - Operator error
  - Table positioning shift
  - Miscalibrated gradients
  - High B_o inhomogeneities

Slice Positioning Indicators



- A customized jig my be necessary

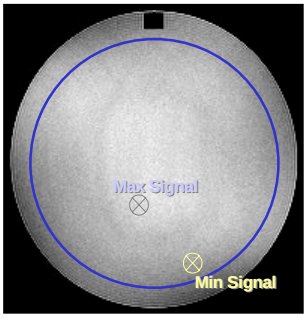
Image Uniformity

- Must Pass on ACR T1-Weighted and ACR T2-Weighted Axial Series ONLY
- Proper Region-of-Interests must be Defined
- Percent Integral Uniformity $\geq$ 90%

Image Uniformity

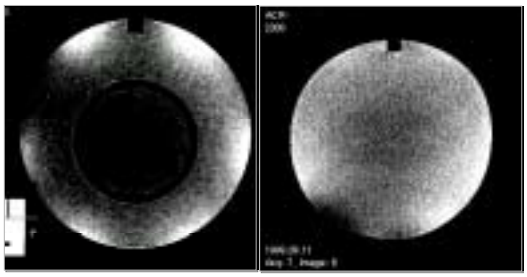
Big ROI = 195 cm² (19,500 mm²)

Small ROI's = 100 mm²



ACR phantom - Slice #7

Uniformity Pattern



Birdcage Coil
High Field

Solenoid Coil
Low Field

Image Intensity Uniformity

- Performance criteria: PIU $\geq$ 90%

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

- 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

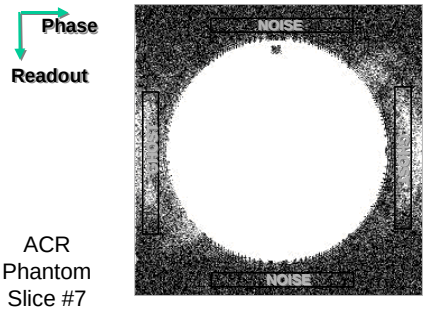
Image Intensity Uniformity

- Causes of failure:
  - Poor phantom centering in head coil (usually AP)
  - Ghosting
  - Motion or vibration
  - Mechanical failure in head coil

Percent Signal Ghosting

- Must pass on slice #7 of ACR T1-Weighted Axial Series ONLY
- Ghost signal is measured and reported as percentage of the signal in the true image
- Ghosting in other images may be counted as "Unacceptable Artifact"

Percent Signal Ghosting



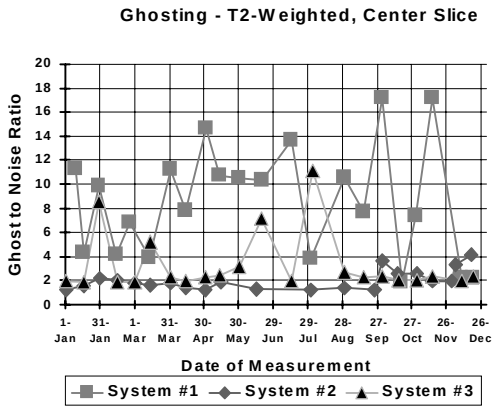
ACR Phantom Slice #7

Percent Signal Ghosting

Measurements
- Use slice 7 of ACR T1.
- Make large ROI (200-215 cm²). Record mean.
- Make elliptical or rectangular ROI's (10 cm² with 4:1 ratio). Record mean of each ROI.

$$\text{Ghosting Ratio} = \frac{|(\text{top} + \text{bottom}) - (\text{left} + \text{right})|}{2 \times \text{large ROI}}$$

Pass Criterion : GR ≤ 2.5%



Ghosting is Nonspecific

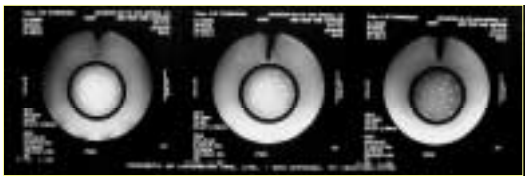
- Instability in MRI signal from pulse to pulse
- Phantom motion
- Loose connections or bad cable
- Partial failure of radio frequency coils
- Pulse sequence calibration error
  - Eddy currents in Fast Spin Echo series

Small Ghosting

- Small amounts of ghosting may not be above GR limits
- May still cause failure

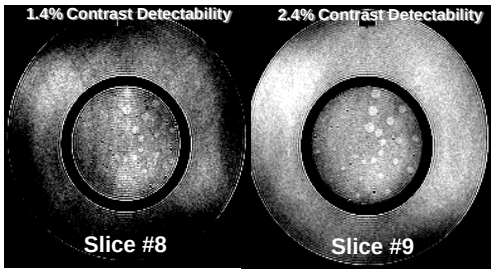
Low-Contrast Detectability

- Slices 8-11, both ACR series
- Adjust window/level for optimum contrast
- Uses partial volume artifact to advantage
  – thickness of plastic membrane used to adjust contrast



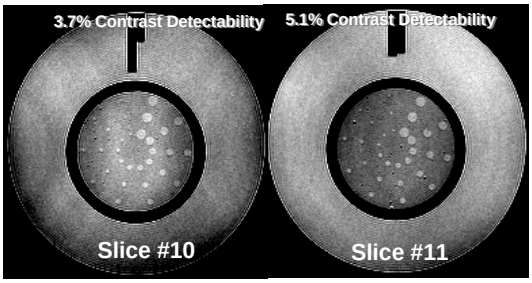
Low Contrast Detectability

Four sets of plastic membranes with holes 1.5 mm to 7 mm in diameter

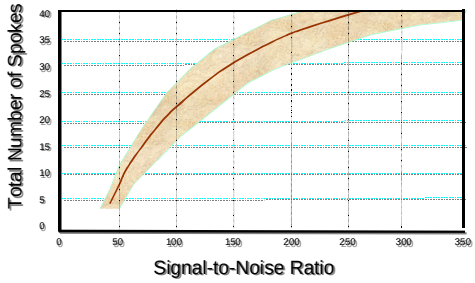


Low Contrast Detectability

Partial volume effect used to obtain contrast from membranes of variable slice thickness



LCD and Signal-to-Noise



Low-Contrast Detectability

Performance criteria:

– each ACR series should have a total score of at least 9 spokes.

– Must pass **both** ACR series or **both** site series

Low-Contrast Detectability

- Causes of failure:
  - Incorrectly positioned slices
    - Contrast based on partial volume averaging
  - Tilted phantom
  - Incorrect slice thickness
  - Ghosting
  - Inadequate SNR

LCD Intensity Variation

Suggests poor positioning

Ghosting Artifact

- Ghosting may obscure otherwise visible LCD spokes

Excessive Edge Filter

- Edge filter increases truncation artifact, obscures outer holes of LCD spokes

Susceptibility Artifacts

Small inclusions in LCD insert can hamper test

Summary

- Good understanding of ACR phantom image tests depends on familiarity with common MRI artifacts
- Each test evaluates potential failures of different components of the MRI system