Radiofrequency Coil Quality Control

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THE UNIVERSITY OF TEXAS
MD Anderson Cancer Center
Making Cancer History®

Educational Objectives

- Describe different approaches to performing RF coil quality control testing
- Discuss methods of measuring SNR
- Describe the influence of phantoms, acquisition parameters and post-processing on SNR results
- Recommend information to include in the coil QC record

Outline

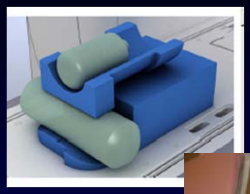
- Purpose of coil QC
- How to perform coil QC
  - Manufacturer/MR system vendor guidance
  - SNR measurement methods
    - Automated and manual methods
  - Phased-array coils and uniformity correction
  - Phantoms
- Factors that will affect results
- What to include in the report
- Challenges

RF Coil QC - purpose

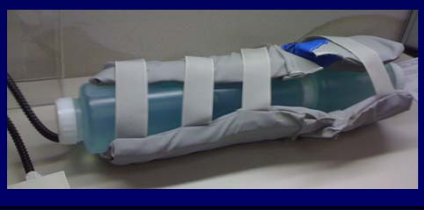
RF coils are a critical component of the MR imaging system. Quality control of RF coils is important:

- To ensure acquisition of high quality diagnostic MR images by ensuring good coil performance
- To catch coil problems before they affect clinical scans
- To troubleshoot clinical image quality problems
- As part of a comprehensive MRI quality assurance program
- Required for ACR accreditation (breast MRI or MRI)

RF Coil Quality Control



RF Coil Quality Control

- Coil inspection
- Measurement of signal-to-noise ratio (SNR)
- Measurement of signal uniformity for volume coils
- Phased array coils: evaluate SNR for individual channels
- New coils: establish baseline coil performance in order to monitor coil performance over time.
- Existing coils: Compare SNR results to baselines and/or vendor specifications
- Artifact evaluation (including ghosting)

Coil QC Procedure

- May be provided by coil or MR system manufacturer
  - On-system guidance during automated testing
  - Coil User or Service Manual
- Position of phantom, coil
- Coil configurations, where to landmark
- Pulse sequence and scan parameters
- May include pass/fail SNR limits
  - Lower limit
  - May not provide an upper limit
- May not provide any limits: *"Establish baseline and monitor over time"*

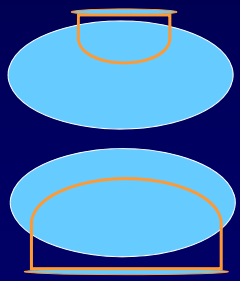
Coil QC Procedure

If vendor guidance is not available

- Use a basic coil QC procedure
  - Spin echo, FSE, GRE
  - Clinically relevant FOV and image orientation
  - If possible acquire images using individual channels
  - Test available coil configurations
- Choose an SNR method to use
- Establish baseline SNR for future comparisons

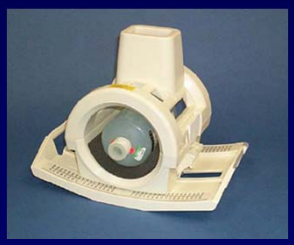
Surface Coils

- Surface coils
  - Highest signal close to body, rapid signal drop-off with depth
- Smaller coils – record less noise, higher SNR than larger coils, but sensitive to smaller anatomical volume
- Larger coils – lower SNR, sensitive to larger anatomical volume



Volume Coils

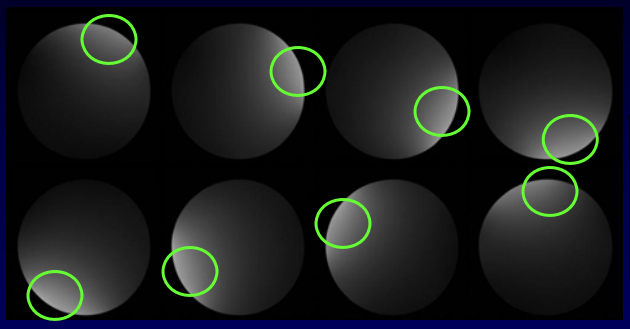
- Volume coils
  - Designed to provide uniform RF field, uniform signal within coil
  - ACR requires uniformity and ghosting measurements



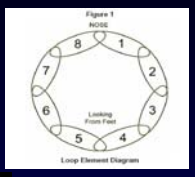
Phased array coils

- Multiple small coil elements, independent receiver channels (8, 12, 16, 32, … more expensive)
- Less noise, higher SNR of small elements
- Small elements – sensitive to shallower depth
- Multiple elements provide anatomical coverage
- Higher SNR can be traded for:
  - Better resolution: larger matrix, thinner slices
  - Shorten scan time or increase number of slices by reducing number of averages
- Enables the ability to do parallel imaging

Phased array coils



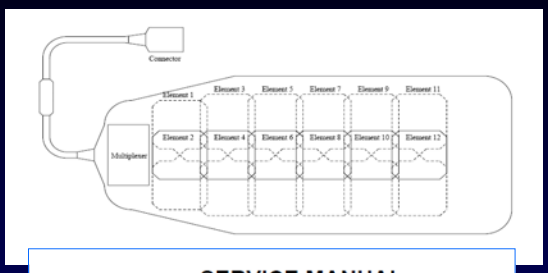
Images with individual channels activated.



Composite image

Invivo 8 ch HR brain array

3T 8 channel CTL array



SERVICE MANUAL

USA Instruments, Inc.

Document 2413107-3

Revision 1

GE Signa® EXCITE™ 3.0T
Premier III Phased Array CTL Spine Coil
(3.0T HD CTL Array)

GE Catalog Part Number: M1385AW

Figure 4: Positioning the coil and phantoms

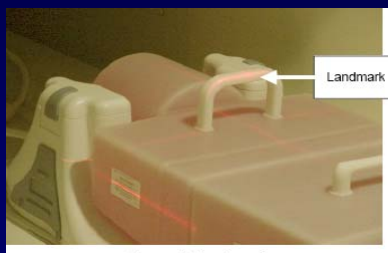


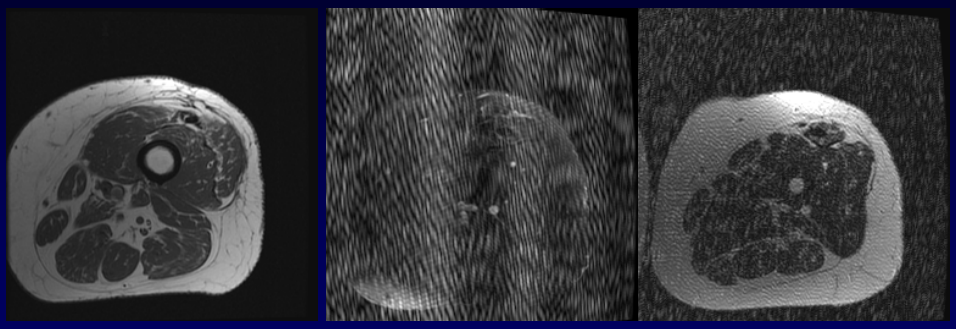
Figure 5: Landmark

Coil inspection

- Inspect coil, cables, cable insulation, ports and connectors for damage
- Could present a safety issue (burns) , result in low SNR or image artifacts.

www.invivocorp.com

Artifacts



Intermittent artifacts - 8 channel body array
"bias fault" in error log

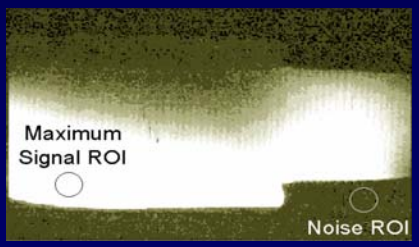
Measuring coil SNR

- Method 1:
  - SNR = mean signal within ROI divided by the noise (std dev of the same ROI or in background)

$$SNR = \bar{S} / \sigma$$

  - This method can be used for surface coils:

Maximum signal ROI / noise std dev

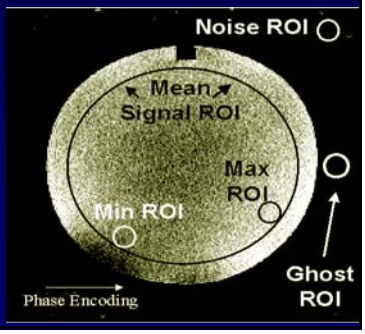


Measuring coil SNR

- Method 2:
  - SNR = 0.655 x mean Signal divided by the std deviation (of an ROI in air)

$$SNR = \sim 0.655\ \bar{S} / \sigma_{air}$$

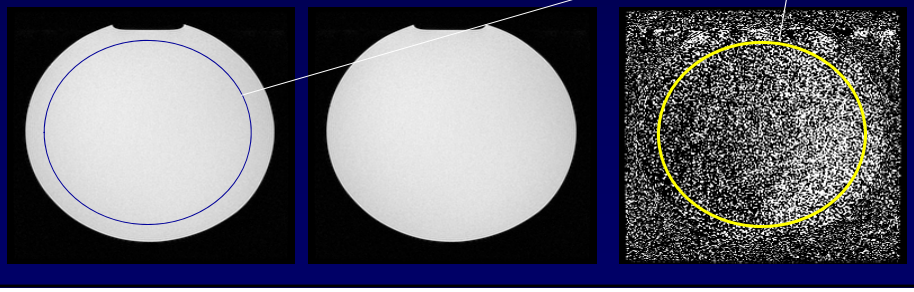
  - 0.655 factor corrects for the background signal in magnitude images having Rician distribution, rather than Gaussian
  - Noise ROI should be placed to avoid artifacts



Measuring coil SNR

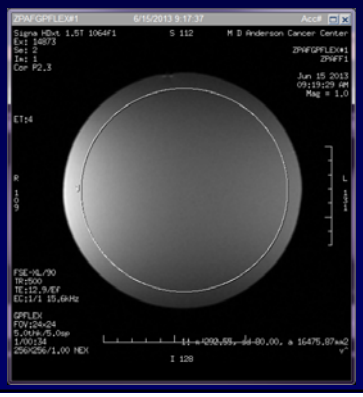
- Method 3: (NEMA subtraction)
  - Acquire 2 images with exactly same parameters
  - Subtract one image from the other
  - SNR = √2 x mean signal of ROI in one image / std dev of ROI in subtracted images.

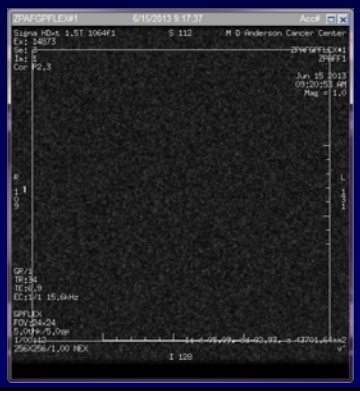
$$SNR = \sqrt{2}\ \bar{S} / \sigma$$



Measuring coil SNR

- Method 4:
  - Acquire signal image
  - Turn off RF excitation (service mode) – acquire noise image
  - Noise value is the standard deviation of ROI in noise image

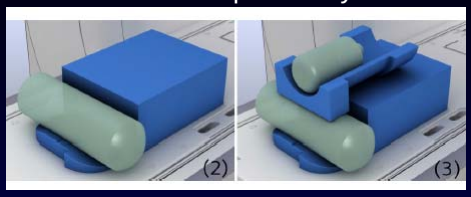




$$SNR = \bar{S} / \sigma$$

Automated Coil QC

32 channel Spine Array

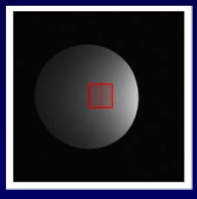


Magnetom Aera, Skyra Operator Manual – Coils, Siemens

- Siemens AERA
- Service mode not required.
- Reports (pdf) available

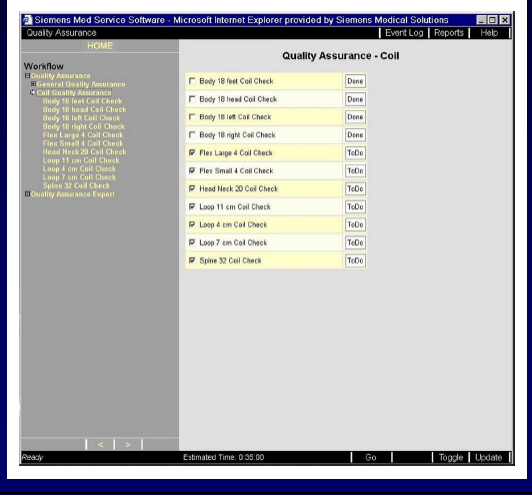
Summary

	Status
098_Spine_32_SP1_Tra	OK
098_Spine_32_SP2_Tra	OK
098_Spine_32_SP3_Tra	OK
098_Spine_32_SP4_Tra	OK
098_Spine_32_SP5_Tra	OK
098_Spine_32_SP6_Tra	OK
098_Spine_32_SP7_Tra	OK
098_Spine_32_SP8_Tra	OK
Program Result	Success



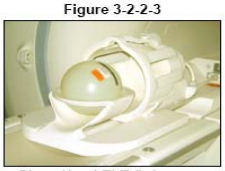
S/N

Parabola Fit	
Value	Min
42.5	29.0



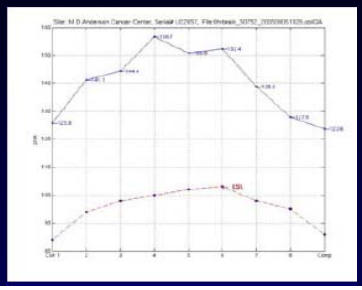
Automated Coil QC

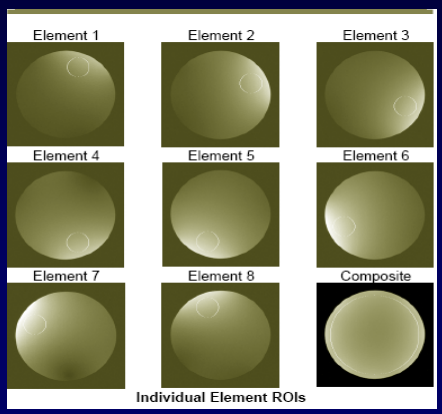
Figure 3-2-2-3



Place Head TLT Sphere on Phantom Ring

- GE
- Uses NEMA method
- Accessible through Service Tools





Individual Element ROIs

EXAMPLE OUTPUT OF TOOL - TABLE 3-2-3-1

```
phantom center =(131,137)
Individual Element NEMA SNR from composite images
ROI       signal      noise       snr
 1        1835.0      19.39     133.8
 2        2054.6      19.61     148.1
 3        2117.0      19.44     154.0
 4        2005.0      19.79     143.3
 5        1994.5      19.49     144.7
 6        2080.0      19.70     149.3
 7        2029.9      20.24     141.8
 8        1848.8      20.19     129.5
mean      1995.6      19.73     143.1
stdev      102.8       0.33       8.1
stdev%       5.2       1.66       5.7
Composite SNR Using NEMA Method
ROI       signal      noise       snr
 C        1920.1      19.99     129.8
serial number U7514 bay3a
```

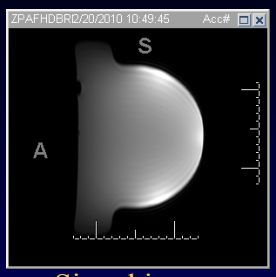
Using ROIs shown in Figure 3-2-2-5 signal is measured on each of the two composite images and averaged. The same ROI for each element is used to measure noise on the one filtered difference image

Composite image results

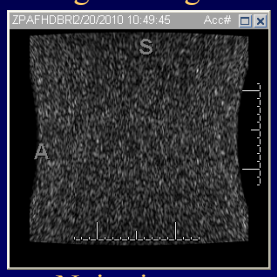
Automated Coil QC

- 8 channel HD breast array
- Automated test uses NEMA method
- Text file saved on scanner, but access requires knowledge of Unix

```
#units N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A
#label Test_Number Signal_Image Scale_Factor ISNR_Spec ISig
Noise ISNR Scaled_ISNR Comb_Rows Comb_Cols
#pass_fail PASS
#coil_name 1.5T_HD_8Ch_VIBRANT_Breast_Array_by_GE
#pass_number 1
#coil_serial 355
#num_tests 2
#logical_coil_1 HDBreastRight
#logical_coil_2 HDBreastLeft
#end
1 1 100000 55 3.21115e+07 2.88438 1.11329e+07 111.329 512 512
1 2 100000 38 1.78698e+07 2.2741 7.85794e+06 78.5794 512 512
1 3 100000 38 1.72263e+07 2.23221 7.71715e+06 77.1715 512 512
1 4 100000 49 2.6328e+07 2.57603 1.02204e+07 102.204 512 512
2 1 100000 31 3.07728e+07 2.50426 1.22882e+07 122.882 512 512
2 2 100000 32 1.48915e+07 2.09001 7.12505e+06 71.2505 512 512
2 3 100000 35 1.95082e+07 2.43653 8.00652e+06 80.0652 512 512
2 4 100000 53 3.27164e+07 2.8745 1.13816e+07 113.816 512 512
```



Signal image



Noise image

Signal Intensity Corrections

Signal intensity correction algorithms designed to improve image uniformity when using phased array coils:

- SCIC, PURE (GE), CLEAR (Philips), Normalize, pre-scan Normalize (Siemens)

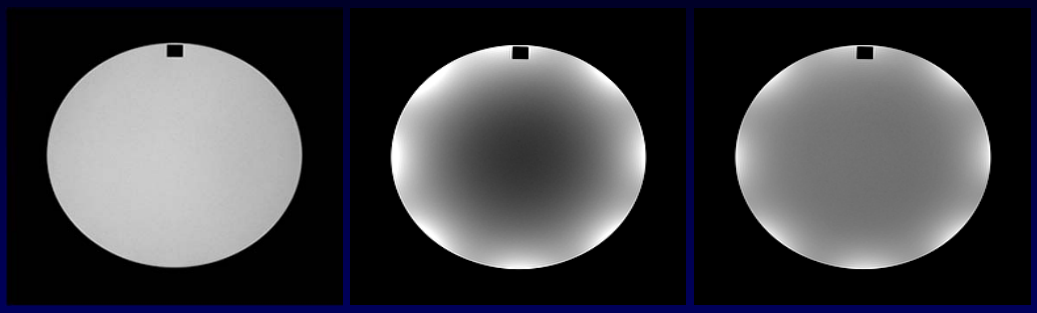
Advantages:

- Provides more uniform clinical images.
- Needed for multi-channel phased array head coils to pass ACR PIU test.

Turn off for coil QC:

- Can mask coil element failures.
- Changes signal and noise distribution in the image (SNR, PIU)

Signal Intensity Corrections



Quad head coil

1.5T
8 channel brain array
SNR = 269
PIU = 76.3%

1.5T
8 channel brain array
with SCIC
SNR = 364
PIU = 92%

Phantoms and SNR

Phantoms:

- Fluid filled, various shapes and sizes.
- Water doped with paramagnetic substance to create T1 and T2 relaxation times similar to tissue, and $NaCl_2$ for similar conductivity.
  - $NaCl + CuSO_4$
  - $NaCl + NiCl_2$ (e.g. ACR phantom, less temperature dependent)
- 3T phantoms may be oil filled to reduce RF penetration and dielectric effects.

Phantoms and SNR

Spin echo sequence
1.5T 8Ch HR Brain array

Factors that affect SNR, detection of bad coil elements

Scan parameters

- Pulse sequence, scan parameters (TR/TE, receive bandwidth, # averages, matrix, slice thickness, FOV, …)
- Coil configuration
- Application of intensity corrections
- Use of parallel imaging – don't use

Setup and analysis

- Phantom, fill solution
- Phantom position within the coil
- Size and position of ROIs

RF Coil Quality Control

Use consistent scan/measurement methods:

Identical phantom and positioning within coil

- Homogeneous phantom (sphere, cylinder, block, custom)
- Use the same phantom every time

Identical scan parameters:

- Pulse sequence, timing parameters (TR, TE), flip angle, slice thickness and position, matrix, FOV, receive bandwidth, etc
- Record transmit gain/attenuation, receiver gains

Identical measurement methods, ROI positions

- Signal, noise, SNR, signal uniformity, ghosting
- Evaluation of channel performance

Record procedure (photo of setup, ROI positions, scan parameters)

RF Coil Quality Control

Coil testing:

- Follow manufacturer procedure or develop your own.
- Manufacturer may be more likely to respond to coil QC failure when their QC procedure is followed.

Uniformity:

- Follow procedure in 2004 ACR MRI QC Manual or vendor's procedure if available
  - Volume coils: min, max signal intensity within large ROI
  - Surface coils: min, max signal intensity

RF Coil Quality Control

Artifact evaluation

- Evaluate images acquired using QC protocol
- Volume coils: measure ACR ghosting ratio
- To troubleshoot artifacts observed on patient images may acquire images of homogeneous QC phantom using clinical protocol.

Functional checks

- Verify that all coil configurations function
- Verify that the coil functions in all ports
- Record any error messages

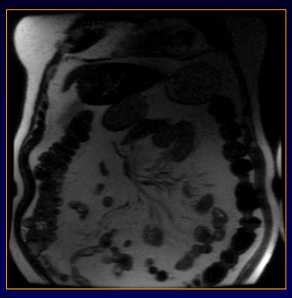
RF Coil Quality Control

Coil testing:

- Important to test coils:
  - after installation of new scanner or new coils
  - at least annually
  - whenever artifacts or coil problems occur

Clinical example

Signal loss – superior anterior element of 1.5T 8 channel body array



Configuration:
8 ch body Full FOV

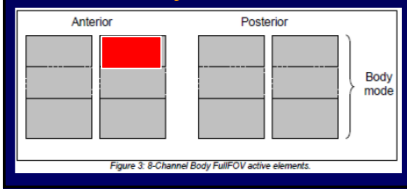
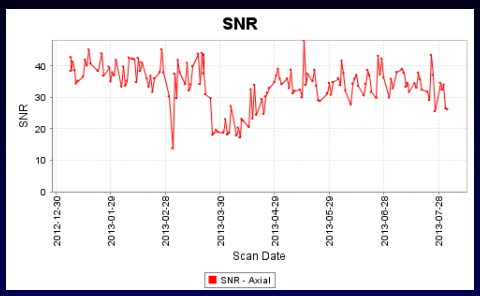


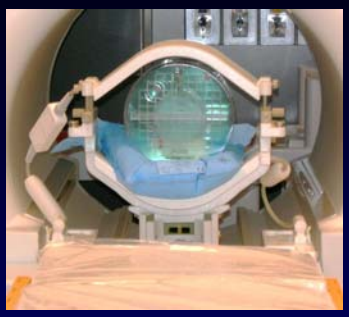
Figure 3: 8-Channel Body FullFOV active elements.

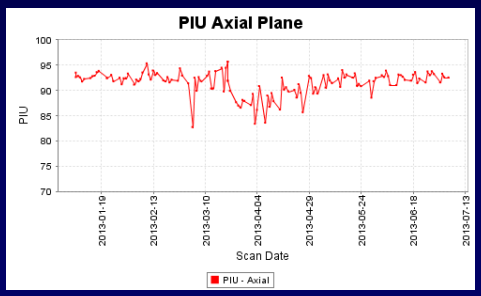
Configuration:
8 ch body Upper

Figure 1: 8-Channel Body Upper active elements.

RF Coil Quality Control

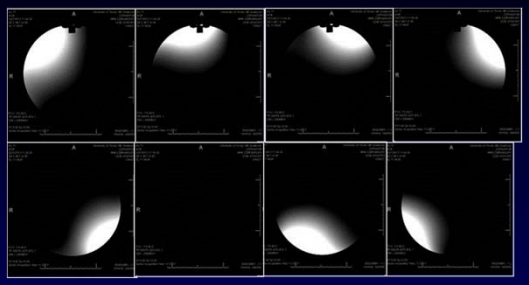


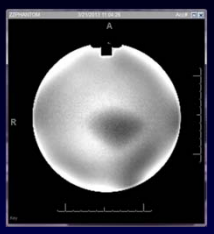




Noras 8 channel OR head coil,
Noras MRI Products, www.noras.de

RF Coil Quality Control

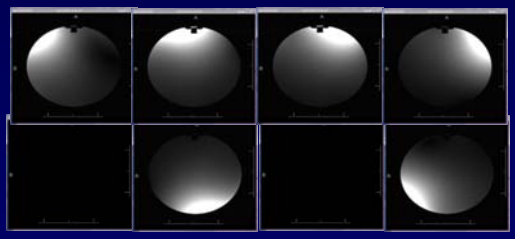


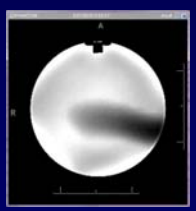


Composite image

3/21/2013
ACR phantom
Slice 7 from daily QC

SNR = 43
PIU = 93.3%





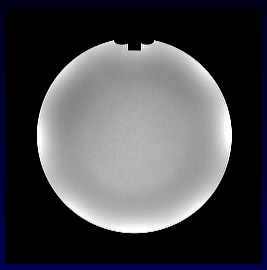
Composite image

4/21/2013
ACR phantom
Slice 7 from daily QC

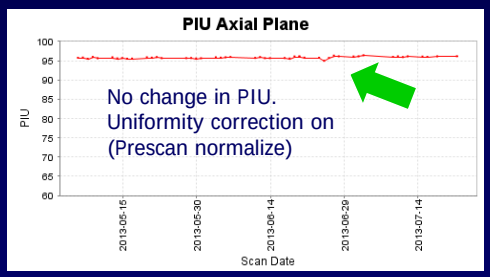
SNR = 21
PIU = 84.8%

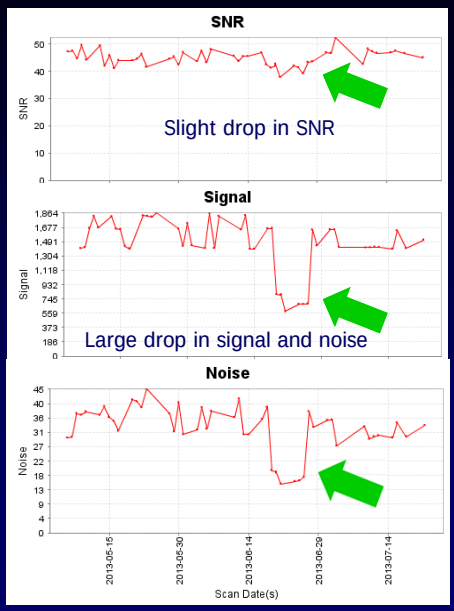
Daily QC: 2 anterior elements failed

Siemens 20-channel head-neck array



ACR Phantom Slice 7





Causes of Failure

- Port failure – coil may work in one port but not another
- Preamplifiers
- Coil elements
- 16ch switch
- Coil cables
- Coil connectors, pins

Coil QC Report

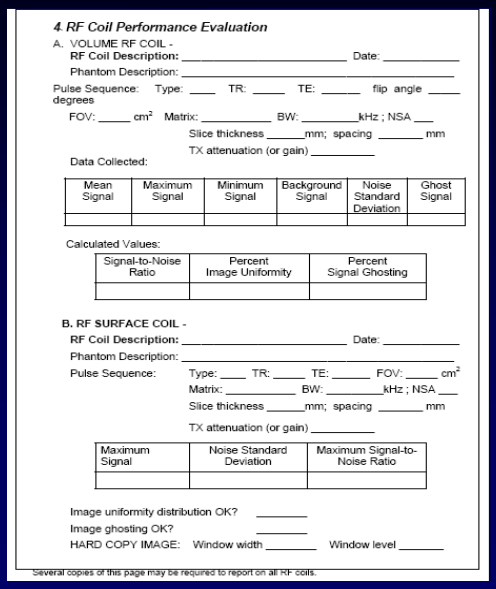
- Coil description
  - Manufacturer, model, serial number
  - Scanner used for testing
- QC Method
  - Pulse sequence, scan parameters (TR/TE, bandwidth, averages, FOV, slice thickness/spacing, matrix), applied filters, etc
  - Transmit and receiver gains
  - Phantom, position within coil (photo)
  - SNR measurement method used
  - Position of signal and noise ROIs (photo/screen cap)

Coil QC Report

- Measurements:
  - SNR, uniformity, ghosting
  - Artifact evaluation
  - Limits and source of limits (e.g. baseline, coil manual)
  - Pass/fail results
  - Date
  - Physicist

RF coil report (ACR)

- Volume coil:
  - SNR
  - Percent signal ghosting
  - Percent uniformity
- Surface coil
  - Maximum SNR



4. RF Coil Performance Evaluation

A. VOLUME RF COIL -
RF Coil Description: _____ Date: _____
Phantom Description: _____
Pulse Sequence: Type: ____ TR: _____ TE: _____ flip angle _____ degrees
FOV: _____ cm² Matrix: _____ BW: _____kHz ; NSA ___
Slice thickness _____mm; spacing _____ mm
TX attenuation (or gain) _____
Data Collected:

Mean Signal	Maximum Signal	Minimum Signal	Background Signal	Noise Standard Deviation	Ghost Signal

Calculated Values:

Signal-to-Noise Ratio	Percent Image Uniformity	Percent Signal Ghosting

B. RF SURFACE COIL -
RF Coil Description: _____ Date: _____
Phantom Description: _____
Pulse Sequence: Type: ____ TR: _____ TE: _____ FOV: _____ cm²
Matrix: _____ BW: _____kHz ; NSA ___
Slice thickness _____mm; spacing _____ mm
TX attenuation (or gain) _____

Maximum Signal	Noise Standard Deviation	Maximum Signal-to-Noise Ratio

Image uniformity distribution OK? _____
Image ghosting OK? _____
HARD COPY IMAGE: Window width _____ Window level _____
Several copies of this page may be required to report on all RF coils.

Challenges

- Phased array coils:
  - 8-, 12-, 16-, 32-, ….128-channel arrays
  - Ideally should test individual channels
  - Not all vendors provide automated test tools
  - Manual measurements are time consuming
  - Need tools for physicists in the field
- AAPM MR Subcommittee Task Group

Which is not appropriate for coil QC?

1. Spin echo pulse sequence
2. Image evaluation for artifacts
3. Application of signal intensity correction
4. Use of the same phantom and setup
5. Measurement of uniformity for volume coils

Answer: 3. Application of signal intensity correction

Reference: AAPM Report 100

Coil element failure in a multi-channel phased array coil

1. Will always be visible in the composite image
2. Will always be apparent by a failing PIU value
3. Will be demonstrated by excessive ghosting
4. Is best demonstrated by acquiring phantom images with individual elements
5. Is not an issue for clinical images

Answer: 4. Is best demonstrated by acquiring phantom images with individual elements

Reference: AAPM Report 100

Which statement is false? Coil QC phantoms

1. Should be homogenous or have a homogeneous section
2. Are interchangeable
3. Contain fill solution with conductivity and relaxation properties similar to tissue
4. Should conform to the coil shape
5. Provide uniform signal for SNR and uniformity determination

Answer: 2. Are interchangeable
Reference: ACR Magnetic Resonance Imaging QC Manual, 2004.

References

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3. Dietrich et al, Measurement of Signal-to-Noise Ratios in MR Images: Influence of multichannel coils, parallel imaging, and reconstruction filters, JMRI, 26(2), 2007.
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5. Reeder, Measurement of Signal-to-Noise Ratio and Parallel Imaging, in Parallel Imaging in Clinical MR Applications, 2007.