Tips, Tricks, and Hidden Obstacles for RF Coil Testing

Tips to Avoid Being Fooled

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Disclosures

I am employed by ViewRay, Inc.

In the past: I have worked for Picker, Philips, and Alltech

Goals of this talk

- Avoid being fooled by your own measurements
- Instill confidence in your testing
  - Understand what is being measured
  - Ensure you are measuring something useful and reproducible
- Help you avoid common pitfalls and mistakes
  - There are a lot of hidden events in image production
- Know when there is a problem
  - Be able to prove it
  - Take the subjectivity out it (if possible)

Organization of this talk

- Statements
  - Based on literature or common knowledge
- My Take
  - Based on my interpretation and project needs
- My Approach
  - Based on practical design
- My Warnings
  - Based on experience

It is not magic, but it might as well be.

NEMA Standards – good place to start

Some familiarity with the NEMA standards will help
- They can be downloaded for free

NEMA Standards Publication MS 1-2008 (R2014)
Determination of Signal-to-Noise Ratio (SNR) in Diagnostic Magnetic Resonance Imaging

NEMA Standards Publication MS 3-2008 (R2014)
Determination of Image Uniformity in Diagnostic Magnetic Resonance Images

NEMA Standards Publication MS 6-2008 (R2014)
Determination of Signal-to-Noise Ratio and Image Uniformity for Single-Channel Non-Volume Coils in Diagnostic MR Imaging

NEMA Standards Publication MS 9-2008 (R2014)
Characterization of Phased Array Coils for Diagnostic Magnetic Resonance Images

Uniformity (not today)

Uniformity is important, yet I am going to ignore it beyond this slide.

Why?
There are a lot of techniques and tools that are used to “level out” uniformity.

SNR issues will draw attention more quickly and painfully
(unless you are a coil designer)

Signal to Noise

SNR is "simply"

$$\frac{Mean\ of\ Signal\ Area}{Image\ Noise}$$

What can become difficult is arguing about the "true" image noise.

Personally, I try to stay out the argument.

Signal to Noise

NEMA standards MS1, MS6, and MS9

Signal can be summarized as:
- The mean of the Measurement Region of Interest (MROI)

Noise determination:
- Generate the "image noise"
- There are four approaches (methods):
  1. Subtract two signal images
  2. Signal image and No RF image
  3. Synthetic two images from one scan
  4. Noise region(s) on same image used for signal

Determining MROI

NEMA standards MS6 and MS9 (and passing reference to MS3)

Some discussion about determining MROI
- Different coil types lead to different sizes and positions
- Some confusion and indecision
  - 121 pixels, Sub-coils, 7 x 7 pixel square, regular shapes, slice location

My Take on RF Coil Testing

Periodic testing should focus on looking for TRENDS or DELTAS

Is the coil meeting the customer need?

Is the coil performing like we expect it to perform?

Is the coil performing like it did before?

"Absolute" coil performance is often best left to accreditation testing.

My Take on RF Coil Testing

- **Find an approach that works for you**

Easily **reproducible** and transferable to others

- Simple setup
- Simple geometry
- Readily available phantoms

My Take on RF Coil Testing

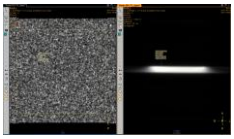
- **Find an approach that works for you**

Each method has advantages and supporters

- Method #1: Subtraction easy to implement
  - Good choice if you are interested in measuring SNR with parallel imaging
- Method #3: Twice as big to make two images
  - Synthetic image creation gives you control
- Method #4: Single image with noise regions
  - Keep the FOV big enough and measure noise in 4 corners
  - Useful for measuring ghosting too
  - Carefull! You can be fooled easily by filtering

My Approach to RF Coil Testing

- To the "non-purist" all methods are equally valid
  - I like and use NEMA method #2: noise image and signal image
  - It is easy to do once a few image production things are countered
  - Stick with your approach (if it is correct)



Noise image (no RF) Signal image

From MS1-2008 (R2014)

2.3.2.2 **Method 2**

A noise scan image is acquired with the phantom in its original position and with no RF excitation. In this situation, it is permitted to decrease TR and accelerate the noise scan acquisition. Ensure that the bandwidth, matrix size and number of signal averages are held constant. Ensure that the MR system does not automatically change other relevant parameters as a result of the above changes.

a. Ensure that the output from the transmitter is such that no NMR signal is generated upon execution of the noise scan. It shall be permitted to turn off the RF amplifier or otherwise suppress the RF excitation.

b. Ensure that the system receiver attenuation (or gain control) and any scaling of the image reconstruction are identical to that of the first scan.

c. Except for TR, the noise image is acquired under the same conditions as [Image 1]. No system adjustment or calibration shall be performed between the scans.

d. Determine the standard deviation, SD, of the pixel values within the MROI on the noise image using Equation 1.

e. If a magnitude image is evaluated, the image noise will not be Gaussian distributed, but rectified to a Rician distribution. The change of noise distribution must be compensated for as the SNR measure assumes the noise is Gaussian distributed. For a single-channel system the correction factor is:

$$\text{Image noise} = \frac{SD}{0.66} \qquad \text{Equation 4}$$

My Approach to RF Coil Testing

Periodic testing is looking for TRENDS or DELTAS

- Relative SNR is fine (stay consistent)
- Constant is just a scale – so set to 1 (stay consistent)

$$\text{SNR} = 1 * \frac{MEAN\ of\ Signal\ MROI}{Standard\ Deviation\ of\ Noise\ Region}$$

- Set the scale! Actual SNR number is not typically important*
- If h and c can be set 1, why not the SNR constant.
- If you are going to publish then get the factor right

* Indicates a heretical statement

My Approach to RF Coil Testing

- **Speed ups are fine as long as you always use the same sequence and phantom for a particular coil.**

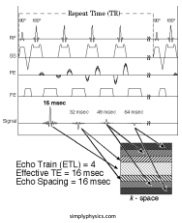
  If you are with me so far then TSE 4 or TSE 8 is okay

  Probably a T1 weighted echo train

  Single slice

  Not-so long TR

  Do NOT use parallel accelerations



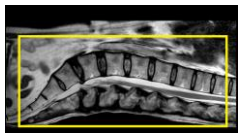
simplyphysics.com

My Approach to RF Coil Testing

- **Is the coil meeting the clinical need?**
- **Does the test reflect the typical use?**

Find an approach that works for you

- Easily reproducible and transferable to others
  - Simple setup
  - Simple geometry
- Use a phantom that matches the use of the coil
  - When in doubt, go bigger because people are big
- Use an MROI that matches the use of the coil
  - Use an MROI that is as big as a user might be use on a person



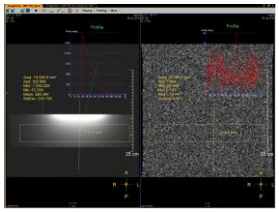
My Approach to RF Coil Testing

- Example single channel loop coil
- SNR = Mean Signal / STD Noise

SNR = 380.464 / 0.603 = 631

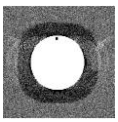
NQ = 1.155 / 0.603 = 1.92

Placement of the MROI matters!

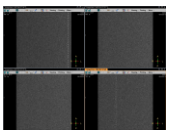


My Warnings about RF Coil Testing

- **Throw away the rules of the past**
  Sum of squares is probably not the default
- **Recon has evolved**
  Adaptive coil combinations are the norm
  denoising
- **Noise is not uniform**
  Coil intensity corrections
  Parallel imaging reconstruction algorithms
  Gradient distortion corrections
  System problems



Simply Physics



My Approach about RF Coil Testing

Quality of the Noise

- Can give a clue about environmental problems

$$Noise\ Quality = \frac{MEAN}{Std\ Dev}$$

See NEMA MS9-2008 Annex A last column

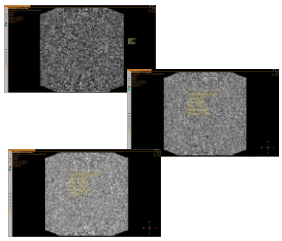
This assumes sum of squares!!!

If the NQ > expected then something noisy is afoot, environment has issues

If the NQ < expected then adaptive combination, noise filtering is engaged, coil selection, coil problem??

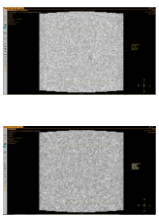
My Warnings about RF Coil Testing

- **Single channel delayed recon**
  NQ = 1.91 (theory = 1.91)
- **3 channel delayed recon**
  NQ = 3.34 (theory = 3.40)
- **4 channel delayed recon**
  NQ = 3.85 (theory = 3.94)



My Warnings about RF Coil Testing

- **16 channel delayed recon good coil**
  NQ = 7.51 (16-ch theory = 7.97; 14-ch theory = 7.45)
- **16 channel delayed recon bogus elements**
  NQ = 6.45 (16-ch theory = 7.97; 11-ch theory = 6.60)
- **Does not exactly hold up, but it is different enough to suggest there is a problem!**



My Warnings about RF Coil Testing

- **Recon scaling***
  - May vary across dynamics or phases
  - Will vary between images series
- **Be careful to force fixed scaling if using multiple image SNR technique**

OR

- **Know how to scale the images relative to each other (not as easy as may seem)**

*Biggest advantage of single image method is that it avoids scaling issues

My Warnings about RF Coil Testing

- **Find recon parameters**
  - If you are doing image and noise as separate images then make sure to use a fixed scaling
  - Example: Philips control parameters and recon control parameters

Will likely need to ask someone

My Warnings about RF Coil Testing

- **DICOM or other image scaling**
  - Non-quantitative MR images are not scaled in an obvious manner
  - DICOM rescale slope and rescale intercept
  - DICOM scale slope and scale intercept
  - Data compression
  - **Stored values versus Displayed values**
  - Can be vendor specific
- **Always look at the images**

My Approach to RF Coil Testing

- **Need to know what variability is "normal"**

  My rule of thumb is +/- 10% MR signal is reasonable

  Sources of variability

  Human factors: care in setting up, speed, experience, motivation

  Environment: humidity, temperature

  Equipment: phantom, coil state, scanner state

Richmond Learns to Park

My Approach to RF Coil Testing

- **Set your threshold for declaring a problem well below the low nominal value.**

  Be able to say, "This coil is clearly not working as it should!"

- **Dead or Alive Test**

  Avoid the temptation to retest until it works!

  Field service engineers will retest until they hit a number. Even the coil failed the test the previous 100 times, it may be declared good if it passes on trial 101.
  (Yes, they do!)*

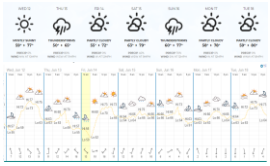
* Indicates a heretical statement

My Warnings about RF Coil Testing

Coil testing and SNR can be like the weather.
Variable and prone to over-simplification.

A number or two probably does not tell the whole story.

High and low temperatures (Fahrenheit or Celsius) are not meaningful to most people.
What is meaningful is do I need a jacket or will I be comfortable wearing shorts? Will I be able to golf?



Cleveland, OH airport
Predictions Fox 8 web site
(low/high chance of rain)

Actual weather from timeanddate.com

Most courses were too wet for golf Friday and Sunday.

My Approach to RF Coil Testing

- **Go the extra step**

  Figure out the variation across testers or phantom and coil arrangement

  Put in the grunt work to figure out what is typical variation for the system

  Do not assume that all systems have the same variation

  Do not assume all coils have the same variation

My Warnings about RF Coil Testing

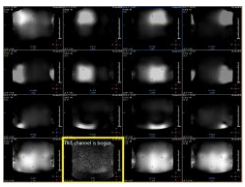
- **Analyze separate coil elements**

  Phase array coils can have bad elements that can go unnoticed by casual users

- **Make sure to look at uncombined images**

  Use the same window/level if possible

  But sometimes you will need to highlight a bogus element



Summary

Understand why you are testing RF coils
- Motivation: Is coil good to use?
- Outcomes: Dead or Alive

Be aware that nonlinear signal processing methods can tease SNR
- Adaptive coil combination, parallel imaging, denoising by default

Get image scaling under control
- Watch out for signal level scaling
- Might need some help or at least guidance from vendor

Summary

Reproducibility by design
- Use the easiest, most reliable setup

Measurement setup should reproduce coil use
- MROI should replicate use case

SNR
- Signal and noise each have information
- I like the two image (noise and signal) method
  - Easy to implement (probably already on your scanner)
- Find a solution for your site and build confidence in it

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