NEMA Standards Publication

NEMA MS 9-2008 (R2014)

# American National Standard for Characterization of Phased Array Coils for Diagnostic Magnetic Resonance Images

National Electrical Manufacturers Association

**NEMA Standards Publication MS 9-2008 (R2014)**

*Characterization of Phased Array Coils*
*for Diagnostic Magnetic Resonance Images*

*Published by:*

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## NOTICE AND DISCLAIMER

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# Preamble

This is one of a series of test standards developed by the medical diagnostic imaging industry for the measurement of performance parameters governing image quality of magnetic resonance (MR) imaging (MRI) systems. These test standards are intended for the use of equipment manufacturers, prospective purchasers, and users alike.

Manufacturers are permitted to use these standards for the determination of system performance specifications. This standardization of performance specifications is of benefit to the prospective equipment purchaser, and the parameters supplied with each NEMA measurement serve as a guide to those factors that can influence the measurement. These standards can also serve as reference procedures for acceptance testing and periodic quality assurance.

It must be recognized, however, that not all test standards lend themselves to measurement at the installation site. Some test standards require instrumentation better suited to factory measurements, while others require the facilities of an instrumentation laboratory to assure stable test conditions necessary for reliable measurements.

The NEMA test procedures are carried out using the normal clinical operating mode of the system. For example, standard calibration procedures, standard clinical sequences, and standard reconstruction processes shall be used. No modifications to alter test results shall be used unless otherwise specified in these standards.

The NEMA Magnetic Resonance Section has identified a set of key magnetic resonance image quality parameters. This standards publication describes the measurement of two of these parameters (SNR and Uniformity) for phased array coils.

*Equivalence*

It is intended and expected that manufacturers or others who claim compliance with these NEMA standard test procedures for the determination of image quality parameters shall have carried out the tests in accordance with the procedures specified in the published standards.

In those cases where it is impossible or impractical to follow the literal prescription of a NEMA test procedure, a complete description of any deviation from the published procedure must be included with any measurement claimed equivalent to the NEMA standard. The validity or equivalence of the modified procedure will be determined by the reader.

*Uncertainty of the Measurements*

The measurement uncertainty of the image quality parameter determined using this standards publication is to be reported, together with the value of the parameter. Justification for the claimed uncertainty limits shall also be provided by a listing and discussion of sources and magnitudes of error.

# Foreword

This standards publication is classified as a NEMA standard unless otherwise noted. It is intended for use by manufacturers of MRI systems and accessory equipment and by MRI end users.

It describes a method for evaluating phased array radio-frequency (RF) coils used with MRI systems. Phased array coils consist of multiple receive-only coil elements that are used to detect signals from a limited portion of the anatomy. The output of each coil element, or combined set of elements, is connected to the input of an independent receiver chain that is part of a set of multiple receiver chains. Phased array coils may be composed of surface coils, flexible coils, pairs of coils such as Helmholtz coils, or coils that surround a specific anatomical region as well as combinations of these coils. Phased array coils achieve good signal-to-noise performance because of their increased filling factor and the simultaneous use of smaller, higher signal-to-noise receive coil elements.

The purpose of this procedure is to provide a standard means for measuring and reporting the signal-to-noise ratio (SNR) and uniformity of signal intensity in images acquired with phased array coils. These quantities are helpful in evaluating the impact of system changes on performance or in demonstrating effectiveness for FDA applications.

The measurement methods have been designed for compatibility with existing NEMA methods for determining the SNR and signal intensity uniformity of head, body, and special purpose coil images (see MS 1, MS 3, and MS 6). Evaluations are performed on images generated using standard clinical scan protocols.

This standards publication is intended for use by MRI system manufacturers, manufacturers of accessory equipment (including RF coils), and MRI end users.

This standards publication has been developed by the Magnetic Resonance Section of the Medical Imaging Technology Alliance, a division of the National Electrical Manufacturers Association. User needs have been considered throughout the development of this publication. Proposed or recommended revisions should be submitted to:

Vice President, Technical Services Department
Medical Imaging Technology Alliance/National Electrical Manufacturers Association
1300 North 17th Street, Suite 900
Rosslyn, VA 22209

Section approval of the standard does not necessarily imply that all section members voted for its approval or participated in its development. At the time it was approved, the section was composed of the following members:

Computer Imaging Reference Systems—Norfolk, VA
GE Healthcare, Inc.—Milwaukee, WI
Hitachi Medical Systems America, Inc.—Twinsburg, OH
Invivo—Gainesville, FL
Medipattern Corporation—Toronto, ON, Canada
Medtronic Navigation—Yokneam, Israel
Philips Healthcare—Andover, MA
Siemens Medical Solutions, Inc.—Malvern, PA
Toshiba America Medical Systems—Tustin, CA

# Rationale

This standard makes extensive references to three earlier standards in its treatment of Phased Array coils.  To aid the reader, it is strongly recommended that copies of these earlier standards be on hand while using this standard.  The earlier standards referenced herein are:

- MS 1 *Determination of Signal-to-Noise Ratio (SNR) in Diagnostic Magnetic Resonance Imaging*
- MS 3 *Determination of Image Uniformity in Diagnostic Magnetic Resonance Images*
- MS 6 *Determination of Signal-to-Noise Ratio and Image Uniformity for Single-Channel Non-Volume Coils in Diagnostic MR Imaging*

Phased array coils are constructed to optimize the signal-to-noise ratio (SNR) of images from a restricted volume of interest within the patient. This measurement procedure seeks to estimate the SNR and uniformity inside the imaging volume of the phased array coil.

Phased array coils that consist of volume coil elements (sub-coils) may provide a uniform signal response over the sensitive volume. Therefore in this standard SNR and uniformity for volume sub-coils may be measured and characterized using methods similar to those used for volume coils such as a head or body coil (MS 1 and MS 3).

For some sub-coils used in the construction of a phased array coil, the increased signal-to-noise performance may be accompanied by a loss of image uniformity. While image uniformity is generally a desirable goal, the reduction of signal from areas outside the region of interest can be exploited to reduce motion artifacts or to reduce wrap-around artifacts caused by undersampling when the field of view is small. In this standard, SNR and uniformity of surface coil elements of a phased array is measured using the methods prescribed in MS 6.

The SNR is a sensitive, but rather non-specific, measure of MR system performance. It can be used to assess the effect of alterations in the MR system (excluding the coil), or it can be used to compare the performance of two coils. Given that the sensitivity of some phased array coils is spatially dependent, the assessment of the effect of alterations in the MR system can be achieved by measuring the SNR about a fixed reference point relative to the coil position. Since different phased array sub-coils are designed for different coil-to-tissue distances, it is not possible to fix a single reference position that is appropriate for all sub-coils, complicating direct comparison of different coils. The reference position selected shall approximate the position of the anatomical feature for which the selected sub-coil is used or intended.

The loading of phased array RF coils varies substantially from application to application and even from exam to exam depending on coil placement. Because of these variations, a generic loading scheme is not included in this standard. Since both loaded and unloaded SNR’s are sensitive to changes in the remainder of the MR system (although the loaded SNR may be more representative of clinical conditions), either shall be permitted in this measurement procedure.

Phantoms are objects that contain MR signal producing material and are generally used for SNR and uniformity testing of RF coils.  It is recognized that as field strength (frequency of operation) increases, wavelength effects become more significant, particularly above 64MHz.  Therefore, this standard allows for the use of water-based or non-aqueous (e.g. oil-based) phantom fluids, without regard to field strength or frequency of operation, and emphasizes instead that the phantom fluid that is actually used be adequately specified for purposes of reproducibility.

The use of geometric distortion correction algorithms and image uniformity correction algorithms is becoming increasingly common, and in some situations necessary. Both types of corrections will alter image uniformity results reported in this standard. While it was the original intent of this standard to characterize the coil without these corrections, it is also the intent of the standard to test the coil under typical clinical conditions. .

Multiple measurement procedures are offered for SNR and image uniformity as per the methods of MS1 and MS3. The preferred methods are referred to as primary methods. The primary measurement procedures may require access to MRI system software functions normally available only to the MRI system manufacturer. Other possible methods are referred to as alternate methods. The alternate measurement procedures employ user accessible software functions.

## Scope

This standards publication defines test methods for measuring the signal-to-noise ratio and image uniformity of MR images produced using receive-only phased array coils. Other coil configurations have been addressed in MS 1, MS 3, and MS 6.

# Section 1
# DEFINITIONS

## 1.1 COIL-RELATED DEFINITIONS

### 1.1.1 Sensitive Volume

The sensitive volume is that volume within which the MR signal of a uniform phantom is greater than or equal to 10 percent of the MR signal measured at the reference position.

### 1.1.2 Sensitive Area

The sensitive area is the intersection of an image slice with the sensitive volume and also contains the reference position.

### 1.1.3 Imaging Region of Interest (IROI)

A general term used to define a volume in which a surface coil may produce useful imaging results. The IROI relates to the intended use or application of the coil and should be considered when selecting a reference position and geometry and location of phantom.

### 1.1.4 Reference Position

The reference position is a user selected point within the sensitive volume of the coil. Typically this is chosen based on the distance of the imaging region of interest from the coil.

### 1.1.5 Phased Array Coils

Phased array coils consist of multiple sub-coil elements that are used to detect signals from a limited portion of the anatomy. The outputs from the receiver chains are digitized, saved, and processed to produce a composite or combined resultant image covering the entire anatomic region of interest.

### 1.1.6 Sub-Coils

A sub-coil is an independent imaging element of a phased array coil structure. The output of the sub-coil is connected to an independent receiver chain or combined together with another sub-coil by analog means and then connected to an independent receiver chain.

### 1.1.7 Sub-Coil Sets (or Modes)

A sub-coil set is a user selectable collection of sub-coils that will be used to image a specific volume of interest (e.g. sets or modes within a large phased array coil)

### 1.1.8 Phased Array - Surface Sub-Coils

A phased array composed of surface sub-coils (e.g. flat loop coil) has elements whose individual sensitivities are spatially dependent and therefore are not expected to produce a uniform signal intensity in the region of interest. Signal-to-noise performance for this type of phased array coil is measured about a reference position within the region of interest.

### 1.1.9 Phased Array - Volume Sub-Coils

A phased array consisting of volume sub-coils (e.g. birdcage coil, saddle coil) has elements whose individual sensitivities are not substantially spatially dependent over the region of interest and therefore are expected to produce relatively uniform signal intensity in the region of interest.

## 1.2 ANALYSIS-RELATED DEFINITIONS

### 1.2.1 Characterization Volume

The characterization volume is a regular geometric volume selected for measurement. The characterization volume shall contain as much of the sensitive volume as is practical, as well as the reference position.

### 1.2.2 Characterization Area

The characterization area is the intersection of an image slice with the characterization volume and also contains the reference position.

### 1.2.3 Measurement Region of Interest (MROI)

A regular geometric area of the image centered at the reference position. For measurement regions containing signal these shall be either a 7x7 square array of pixels, or a circular region containing at least 49 pixels. For measurement regions containing noise information, the array shall be an 11x11 array of pixels, or some other, more complex rectilinear, continuous region, containing at least 121 pixels.

### 1.2.4 Measurement Subregion of Interest (SROI)

In an alternate image uniformity measurement method described in section 2.7, multiple sub regions of interest (SROIs) are defined for measuring image/signal values, each being a 7x7 square array of pixels.

### 1.2.5 Specification Volume

The specification volume is the imaging volume within which a manufacturer guarantees image performance specifications. Images or portions of images outside this volume may not necessarily meet performance specifications, but may still be useful for diagnostic purposes. For head scans, the specification volume must enclose, as a minimum, a 10 centimeter diameter spherical volume (dsv) centered in the RF head coil. For body scans, the specification volume must enclose, as a minimum, a 20-cm dsv centered in the RF body coil. For other volume coils a specification volume may be defined by the manufacturer.

## 1.3 PHANTOM-RELATED DEFINITIONS

### 1.3.1 Signal Producing Volume (Phantom)

For purposes of this standard, SNR and image uniformity/non-uniformity measurements are performed using a homogeneous test phantom. The geometry of this test phantom defines the MR signal producing volume. The phantom geometry defines the characterization volume unless it is larger than the sensitive volume of the coil. It is preferable but not mandatory that the signal producing volume covers or substantially covers the entire sensitive volume of the coil.

## 1.4 IMAGE-RELATED DEFINITIONS

### 1.4.1 Image Artifact

An image artifact is an image anomaly, excluding random noise, that is not representative of the structure or chemistry of the object being scanned, or that is derived from the structure or chemistry of the object being scanned but which appears in the image at a location other than expected.

### 1.4.2 Image Uniformity/Nonuniformity

The signal pixel intensity variation within an image that is repeatable from scan to scan.

An absence of image non-uniformity (N) is defined as N=0% and perfect image uniformity (U) is defined as U=100%. The relationship is: U = 100 - N.

### 1.4.3 Baseline Pixel Offset Value

The baseline pixel offset value is the pixel value for a particular MR system that represents a noise-free signal level of zero.

### 1.4.4 Image Signal

The mean pixel value within the MROI (minus the baseline pixel offset, if any) in the original, unsubtracted image is the image signal.

### 1.4.5 Image Noise

The random variations in pixel intensity in the MROI are called image noise.

### 1.4.6 Image Signal-to-Noise Ratio

The image signal-to-noise ratio is a single number obtained by dividing the image signal by the image noise.

# Section 2
# METHODS OF MEASUREMENT

## 2.1 TEST HARDWARE

### 2.1.1 MR Characteristics of the Signal Producing Volume (Phantom)

The following are the desired MR characteristics of the signal producing volume:

$T_1$ < 1200 milliseconds (at operating field strength)
$T_2$ > 50 milliseconds (at operating field strength)

The phantom geometry, material, additives, and any special preparation procedures, shall be specified with the results to allow reproducibility.

It shall be permitted to use non-aqueous (e.g. oil-based) or water-based phantoms. Take care to select materials and additives that do not cause undue wavelength (“dielectric resonance”) effects at the MR frequency of operation.

If the $T_1$ and $T_2$ properties are different from those stated above, the differences shall be noted with the results.

### 2.1.2 RF Coil Loading Characteristics

A loading scheme is not included in this standard. Since, generally, both loaded and unloaded SNR and uniformity are sensitive to changes in the remainder of the MR system, either shall be permitted in this measurement procedure (see Rationale).

### 2.1.3 RF Coil and Positioning Device

The RF coil to be tested shall be used with its normal positioning device, and placed in a position that is representative of normal use. It is recognized that one may choose to test coils at the magnet center even if typically used in an offset position. In any event, the coil position in the magnet shall be reported with the results.

## 2.2 SELECTION OF MEASUREMENT GEOMETRY

In this section, we describe the requirements for the selection of characterization area(s), based on coil geometry. Given that a particular surface coil may be used for different target anatomies, select one such anatomical use for the coil under test. Place an appropriate signal producing volume (phantom) on the coil. Make the phantom large enough to cover a significant portion of the sensitive volume, and inclusive of a reference position. Where appropriate, the use of a phantom positioning device or holder that is both phantom and coil specific is recommended to allow repeatable placement of the phantom on the coil. Position the coil and phantom combination at either magnet isocenter or the target offset location selected for this particular coil use condition, if such an offset condition (“typical use condition”) is selected for measurement.

### 2.2.1 Selection of the Reference Position , Characterization Volume and Area

In general, phased array coils allow different combinations of active receiving sub-coils to be used simultaneously. For each sub-coil set (or mode), select the reference position, the characterization volume, and characterization area(s). Locate the phantom(s) in relation to the coil to allow scanning of the characterization area(s). For volume sub-coils, the characterization volume shall be the specification volume.

### 2.2.2 Measurement Region-of-Interest (MROI)

For phased array coils consisting of sub-coils that do not produce a uniform signal response over the specification volume (surface sub-coils), SNR and uniformity may be measured and characterized using either of the two methods (primary and alternate) described in NEMA Standard MS 6 (see Rationale). Accordingly, for surface sub-coils, the MROI shall be a 7 x 7 pixel square area of the image centered at the reference position. The mean signal intensity value in this MROI shall be used as the numerator of the SNR. For the alternate measurement procedure for image uniformity, the rectangular area denoted as the ROI shall enclose at least 75% of the characterization area.

For phased array coils consisting of sub-coils that do produce a uniform signal response over the specification volume (volume sub-coils), SNR and uniformity may be measured and characterized using the methods described in NEMA Standards MS 1 and MS 3 (see Rationale). Accordingly, for volume sub-coils, the MROI shall consist of a centered, regular geometric area enclosing at least 75% of the characterization area.

### 2.2.3 Noise Evaluation Area

For volume sub-coils, the noise evaluation area is defined and measured as specified in MS 1.

For surface sub-coils, the noise evaluation area is defined and measured as specified in MS 6.

### 2.2.4 Slice Positions

For volume sub-coils, image uniformity data shall be acquired as single slice scans through the reference position in each of the three orthogonal imaging planes. Image uniformity shall be evaluated using MS 3.

For volume sub-coils, SNR is evaluated using one of the image uniformity slice planes as specified in MS 1.

For surface sub-coils, image uniformity shall be measured in two orthogonal planes which pass through the reference position, using the methods specified in section 2.2.2. The slice plane orientations will be selected to demonstrate the falloff of signal away from the coil structure. This also facilitates measurement of the distance between the coil and the reference position on the images.

For surface sub-coils, SNR is evaluated in one of the image uniformity slice planes using methods specified in section 2.2.2.

In all cases, the slice positions shall be indicated on the drawing that accompanies the measurement results (see Section 3).

## 2.3 SCAN CONDITIONS

Use the scan conditions as specified in MS 6.

## 2.4 MEASUREMENT PROCEDURE

As previously indicated (see Section 2.2.1), the first step in characterizing phased array coil SNR and image uniformity is to select the individual sub-coil, or set of sub-coils, that is to be activated in the region to be imaged. More than one set of measurements (for both SNR and uniformity) may be required depending on the number of sub-coil sets, and the range of anatomic features covered by the phased array coil (e.g. cervical-thoracic-lumbar [CTL] coil).

For each individual sub-coil or set of sub-coils selected, uniformity may be measured by the following methods:

For volume sub-coils utilize the methods of MS 3. Specify which method in MS 3 is used.

For surface sub-coils utilize the methods of MS 6. Specify which method in MS 6 is used.

For each individual sub-coil or set of sub-coils selected, SNR may be measured by the following methods:

For volume sub-coils utilize the methods of MS 1. Specify which method in MS 1 is used.
For surface sub-coils utilize the methods of MS 6. Specify which method in MS 6 is used.

1)

Note that when computing the noise statistics the number of signal channels used to produce the magnitude image alters the Rayleigh noise distribution. Annex A provides a table of appropriate correction factors that shall be applied. A ratio of the corrected noise statistics computed from both the mean and the standard deviations of the noise measurement region can also be used as a possible quality check per Henkelman, R. M. “Measurement of Signal Intensities in the Presence of Noise in MR Images.” Medical Physics 12 (1985): 232-33. And erratum: Vol 13 (4): 544.

# Section 3
# REPORTING OF RESULTS

## 3.1 REPORTING OF SNR

### 3.1.1 Geometric Information

A dimensioned drawing (or drawings) showing the following geometric information must accompany the statement of image SNR for each phased array sub-coil combination (mode):

- Main magnetic field ($B_0$) direction and strength
- Position of the phased array coil with respect to the gradient isocenter
- Position of the characterization volume with respect to the coil structure
- Size and shape of the characterization volume
- Position of the slice within the characterization volume and resulting characterization area
- Position of the MROI within the characterization volume (this also defines the reference position)
- Size and shape of the noise evaluation area and its position relative to the MROI

### 3.1.2 Data Acquisition Parameters

The following data acquisition parameters must accompany the statement of image SNR:

| Parameter | Dimension |
|---|---|
| **Phantom related parameters** | |
| Phantom filler $T_1$ | milliseconds |
| Phantom filler $T_2$ | milliseconds |
| Phantom filler specific conductance (or phantom filler chemical composition) | siemens per meter |
| Phantom dimensions | millimeters |
| **Acquisition related Parameters** | |
| Pulse sequence name/type | …. |
| Pixel bandwidth | hertz per pixel |
| Voxel dimensions | millimeters |
| Field of view | centimeters |
| Slice thickness | millimeters |
| Sequence repetition time (TR) | milliseconds |
| Echo delay time (TE) | milliseconds |
| Number of signals averaged (NSA) | …. |
| Data acquisition matrix size | …. |
| Receive/Transmit coil(s) used | …. |
| **Scanner related parameters and scan conditions** | |
| Software version | …. |
| Statement of geometric distortion correction algorithm | … |
| Statement of RF receive coil correction algorithm | … |
| Type of signal filters used (time and/or image domain) | … |
| Scan room temperature | ºC |
| Phantom temperature | ºC |

If a single spin-echo imaging technique is not used then sufficient sequence information is to be provided with the test report that the imaging test conditions can be reproduced.

A description of the coil loading, if used, shall be provided. If it was not possible to turn off all user-selectable filters (see Section 2.3), the filter that was used shall be noted. If gradient distortion/warp correction methods are used this shall be noted in the results. If RF non-uniformity correction is used this shall be noted in the results.

In addition, any other parameters required to ensure repeatability shall be reported.

#### 3.1.3 SNR Results

The SNR value computed for each sub-coil set shall be reported. Indicate which method was used to characterize SNR from MS 1 or MS 6. The SNR results shall also be reported with and without gradient distortion/warp correction and RF uniformity correction (if it is possible to turn these corrections off).

If an alternate method was used, this shall be specified with the result.

### 3.2 REPORTING OF UNIFORMITY

#### 3.2.1 Geometric and Phantom Information

The parameters listed in Section 3.1.1 must accompany the image nonuniformity results.

#### 3.2.2 Data Acquisition Parameters

The parameters listed in Section 3.1.2 must accompany the image nonuniformity results.

#### 3.2.3 Uniformity Results

The uniformity results computed for each sub-coil set shall be reported. Indicate which method was used to characterize uniformity from MS 3 or MS 6. The uniformity results shall also be reported with and without gradient distortion/warp correction and RF uniformity correction (if it is possible to turn these corrections off).

### 3.3 UNCERTAINTY OF MEASUREMENTS

The measurement uncertainty of the image quality parameters determined is to be reported, together with the value of the parameter. Justification for the claimed uncertainty limits shall also be provided by a listing and discussion of sources and magnitudes of error.

# Annex A
# APPROPRIATE CORRECTION FACTORS FOR MULTI-CHANNEL NOISE STANDARD DEVIATION COMPUTATIONS

When computing the noise standard deviation from multi-channel magnitude reconstructed images, a correction factor is required to produce the appropriate equivalent Gaussian noise statistic. Multi-channel noise statistics can be computed from either the mean of the noise ROI or from the standard deviation of the noise ROI, but different correction factors are to be applied. The appropriate correction factor also varies as a function of the number of image channels combined. Use the table provided here to determine the correct correction factor.

| Number of complex channels | Divide the measured mean of the rectified noise by this factor to derive the corrected standard deviation (symmetric normal distribution) of the noise. | Divide the measured standard deviation of the rectified noise by this factor to derive the corrected standard deviation (symmetric normal distribution) of the noise. | The ratio of (mean/stddev) correction factors. This can be a useful quality test of measured noise statistics. |
|---|---|---|---|
| 1 | 1.25 | 0.66 | 1.91 |
| 2 | 1.88 | 0.68 | 2.75 |
| 3 | 2.35 | 0.69 | 3.40 |
| 4 | 2.74 | 0.70 | 3.94 |
| 5 | 3.08 | 0.70 | 4.42 |
| 6 | 3.39 | 0.70 | 4.85 |
| 7 | 3.68 | 0.70 | 5.25 |
| 8 | 3.94 | 0.70 | 5.61 |
| 9 | 4.18 | 0.70 | 5.96 |
| 10 | 4.42 | 0.70 | 6.29 |
| 11 | 4.64 | 0.70 | 6.60 |
| 12 | 4.85 | 0.70 | 6.89 |
| 13 | 5.05 | 0.70 | 7.18 |
| 14 | 5.24 | 0.70 | 7.45 |
| 15 | 5.43 | 0.70 | 7.71 |
| 16 | 5.61 | 0.70 | 7.97 |
| 17 | 5.79 | 0.70 | 8.22 |
| 18 | 5.96 | 0.70 | 8.46 |
| 19 | 6.12 | 0.70 | 8.69 |
| 20 | 6.29 | 0.70 | 8.92 |
| 21 | 6.44 | 0.71 | 9.14 |
| 22 | 6.60 | 0.71 | 9.35 |
| 23 | 6.75 | 0.71 | 9.57 |
| 24 | 6.89 | 0.71 | 9.77 |
| 25 | 7.04 | 0.71 | 9.98 |
| 26 | 7.18 | 0.71 | 10.17 |
| 27 | 7.31 | 0.71 | 10.37 |

| Number of complex channels | Divide the measured mean of the rectified noise by this factor to derive the corrected standard deviation (symmetric normal distribution) of the noise. | Divide the measured standard deviation of the rectified noise by this factor to derive the corrected standard deviation (symmetric normal distribution) of the noise. | The ratio of (mean/stddev) correction factors. This can be a useful quality test of measured noise statistics. |
|---|---|---|---|
| 28 | 7.45 | 0.71 | 10.56 |
| 29 | 7.58 | 0.71 | 10.75 |
| 30 | 7.71 | 0.71 | 10.93 |
| 31 | 7.84 | 0.71 | 11.11 |
| 32 | 7.97 | 0.71 | 11.29 |
| 33 | 8.09 | 0.71 | 11.47 |
| 34 | 8.22 | 0.71 | 11.64 |
| 35 | 8.34 | 0.71 | 11.81 |
| 36 | 8.46 | 0.71 | 11.98 |
| 37 | 8.57 | 0.71 | 12.15 |
| 38 | 8.69 | 0.71 | 12.31 |
| 39 | 8.80 | 0.71 | 12.47 |
| 40 | 8.92 | 0.71 | 12.63 |
| 41 | 9.03 | 0.71 | 12.79 |
| 42 | 9.14 | 0.71 | 12.94 |
| 43 | 9.25 | 0.71 | 13.10 |
| 44 | 9.35 | 0.71 | 13.25 |
| 45 | 9.46 | 0.71 | 13.40 |
| 46 | 9.57 | 0.71 | 13.55 |
| 47 | 9.67 | 0.71 | 13.69 |
| 48 | 9.77 | 0.71 | 13.84 |
| 49 | 9.87 | 0.71 | 13.98 |
| 50 | 9.98 | 0.71 | 14.12 |
| 51 | 10.07 | 0.71 | 14.27 |
| 52 | 10.17 | 0.71 | 14.41 |
| 53 | 10.27 | 0.71 | 14.54 |
| 54 | 10.37 | 0.71 | 14.68 |
| 55 | 10.46 | 0.71 | 14.82 |
| 56 | 10.56 | 0.71 | 14.95 |
| 57 | 10.65 | 0.71 | 15.08 |
| 58 | 10.75 | 0.71 | 15.22 |
| 59 | 10.84 | 0.71 | 15.35 |
| 60 | 10.93 | 0.71 | 15.48 |
| 61 | 11.02 | 0.71 | 15.60 |
| 62 | 11.11 | 0.71 | 15.73 |
| 63 | 11.20 | 0.71 | 15.86 |
| 64 | 11.29 | 0.71 | 15.98 |
| 65 | 11.38 | 0.71 | 16.11 |
| 66 | 11.47 | 0.71 | 16.23 |
| 67 | 11.55 | 0.71 | 16.36 |
| 68 | 11.64 | 0.71 | 16.48 |

| Number of complex channels | Divide the measured mean of the rectified noise by this factor to derive the corrected standard deviation (symmetric normal distribution) of the noise. | Divide the measured standard deviation of the rectified noise by this factor to derive the corrected standard deviation (symmetric normal distribution) of the noise. | The ratio of (mean/stddev) correction factors. This can be a useful quality test of measured noise statistics. |
|---|---|---|---|
| 69 | 11.73 | 0.71 | 16.60 |
| 70 | 11.81 | 0.71 | 16.72 |
| 71 | 11.90 | 0.71 | 16.84 |
| 72 | 11.98 | 0.71 | 16.96 |
| 73 | 12.06 | 0.71 | 17.07 |
| 74 | 12.15 | 0.71 | 17.19 |
| 75 | 12.23 | 0.71 | 17.31 |
| 76 | 12.31 | 0.71 | 17.42 |
| 77 | 12.39 | 0.71 | 17.54 |
| 78 | 12.47 | 0.71 | 17.65 |
| 79 | 12.55 | 0.71 | 17.76 |
| 80 | 12.63 | 0.71 | 17.87 |
| 81 | 12.71 | 0.71 | 17.99 |
| 82 | 12.79 | 0.71 | 18.10 |
| 83 | 12.86 | 0.71 | 18.21 |
| 84 | 12.94 | 0.71 | 18.32 |
| 85 | 13.02 | 0.71 | 18.43 |
| 86 | 13.10 | 0.71 | 18.53 |
| 87 | 13.17 | 0.71 | 18.64 |
| 88 | 13.25 | 0.71 | 18.75 |
| 89 | 13.32 | 0.71 | 18.85 |
| 90 | 13.40 | 0.71 | 18.96 |
| 91 | 13.47 | 0.71 | 19.07 |
| 92 | 13.55 | 0.71 | 19.17 |
| 93 | 13.62 | 0.71 | 19.27 |
| 94 | 13.69 | 0.71 | 19.38 |
| 95 | 13.77 | 0.71 | 19.48 |
| 96 | 13.84 | 0.71 | 19.58 |
| 97 | 13.91 | 0.71 | 19.69 |
| 98 | 13.98 | 0.71 | 19.79 |
| 99 | 14.05 | 0.71 | 19.89 |
| 100 | 14.12 | 0.71 | 19.99 |
| 101 | 14.20 | 0.71 | 20.09 |
| 102 | 14.27 | 0.71 | 20.19 |
| 103 | 14.34 | 0.71 | 20.29 |
| 104 | 14.40 | 0.71 | 20.38 |
| 105 | 14.47 | 0.71 | 20.48 |
| 106 | 14.54 | 0.71 | 20.58 |
| 107 | 14.61 | 0.71 | 20.68 |
| 108 | 14.68 | 0.71 | 20.77 |
| 109 | 14.75 | 0.71 | 20.87 |

| Number of complex channels | Divide the measured mean of the rectified noise by this factor to derive the corrected standard deviation (symmetric normal distribution) of the noise. | Divide the measured standard deviation of the rectified noise by this factor to derive the corrected standard deviation (symmetric normal distribution) of the noise. | The ratio of (mean/stddev) correction factors. This can be a useful quality test of measured noise statistics. |
|---|---|---|---|
| 110 | 14.82 | 0.71 | 20.96 |
| 111 | 14.88 | 0.71 | 21.06 |
| 112 | 14.95 | 0.71 | 21.15 |
| 113 | 15.02 | 0.71 | 21.25 |
| 114 | 15.08 | 0.71 | 21.34 |
| 115 | 15.15 | 0.71 | 21.44 |
| 116 | 15.22 | 0.71 | 21.53 |
| 117 | 15.28 | 0.71 | 21.62 |
| 118 | 15.35 | 0.71 | 21.71 |
| 119 | 15.41 | 0.71 | 21.81 |
| 120 | 15.48 | 0.71 | 21.90 |
| 121 | 15.54 | 0.71 | 21.99 |
| 122 | 15.60 | 0.71 | 22.08 |
| 123 | 15.67 | 0.71 | 22.17 |
| 124 | 15.73 | 0.71 | 22.26 |
| 125 | 15.80 | 0.71 | 22.35 |
| 126 | 15.86 | 0.71 | 22.44 |
| 127 | 15.92 | 0.71 | 22.53 |
| 128 | 15.98 | 0.71 | 22.62 |
| 129 | 16.05 | 0.71 | 22.70 |
| 130 | 16.11 | 0.71 | 22.79 |
| 131 | 16.17 | 0.71 | 22.88 |
| 132 | 16.23 | 0.71 | 22.97 |
| 133 | 16.29 | 0.71 | 23.05 |
| 134 | 16.36 | 0.71 | 23.14 |
| 135 | 16.42 | 0.71 | 23.23 |
| 136 | 16.48 | 0.71 | 23.31 |
| 137 | 16.54 | 0.71 | 23.40 |
| 138 | 16.60 | 0.71 | 23.48 |
| 139 | 16.66 | 0.71 | 23.57 |
| 140 | 16.72 | 0.71 | 23.65 |
| 141 | 16.78 | 0.71 | 23.74 |
| 142 | 16.84 | 0.71 | 23.82 |
| 143 | 16.90 | 0.71 | 23.91 |
| 144 | 16.96 | 0.71 | 23.99 |
| 145 | 17.01 | 0.71 | 24.07 |
| 146 | 17.07 | 0.71 | 24.16 |
| 147 | 17.13 | 0.71 | 24.24 |
| 148 | 17.19 | 0.71 | 24.32 |
| 149 | 17.25 | 0.71 | 24.40 |
| 150 | 17.31 | 0.71 | 24.48 |

| Number of complex channels | Divide the measured mean of the rectified noise by this factor to derive the corrected standard deviation (symmetric normal distribution) of the noise. | Divide the measured standard deviation of the rectified noise by this factor to derive the corrected standard deviation (symmetric normal distribution) of the noise. | The ratio of (mean/stddev) correction factors. This can be a useful quality test of measured noise statistics. |
|---|---|---|---|
| 151 | 17.36 | 0.71 | 24.57 |
| 152 | 17.42 | 0.71 | 24.65 |
| 153 | 17.48 | 0.71 | 24.73 |
| 154 | 17.54 | 0.71 | 24.81 |
| 155 | 17.59 | 0.71 | 24.89 |
| 156 | 17.65 | 0.71 | 24.97 |
| 157 | 17.71 | 0.71 | 25.05 |
| 158 | 17.76 | 0.71 | 25.13 |
| 159 | 17.82 | 0.71 | 25.21 |
| 160 | 17.87 | 0.71 | 25.29 |
| 161 | 17.93 | 0.71 | 25.37 |
| 162 | 17.99 | 0.71 | 25.45 |
| 163 | 18.04 | 0.71 | 25.52 |
| 164 | 18.10 | 0.71 | 25.60 |
| 165 | 18.15 | 0.71 | 25.68 |
| 166 | 18.21 | 0.71 | 25.76 |
| 167 | 18.26 | 0.71 | 25.84 |
| 168 | 18.32 | 0.71 | 25.91 |
| 169 | 18.37 | 0.71 | 25.99 |
| 170 | 18.43 | 0.71 | 26.07 |
| 171 | 18.48 | 0.71 | 26.14 |
| 172 | 18.53 | 0.71 | 26.22 |
| 173 | 18.59 | 0.71 | 26.30 |
| 174 | 18.64 | 0.71 | 26.37 |
| 175 | 18.69 | 0.71 | 26.45 |
| 176 | 18.75 | 0.71 | 26.52 |
| 177 | 18.80 | 0.71 | 26.60 |
| 178 | 18.85 | 0.71 | 26.67 |
| 179 | 18.91 | 0.71 | 26.75 |
| 180 | 18.96 | 0.71 | 26.82 |
| 181 | 19.01 | 0.71 | 26.90 |
| 182 | 19.07 | 0.71 | 26.97 |
| 183 | 19.12 | 0.71 | 27.05 |
| 184 | 19.17 | 0.71 | 27.12 |
| 185 | 19.22 | 0.71 | 27.19 |
| 186 | 19.27 | 0.71 | 27.27 |
| 187 | 19.33 | 0.71 | 27.34 |
| 188 | 19.38 | 0.71 | 27.41 |
| 189 | 19.43 | 0.71 | 27.49 |
| 190 | 19.48 | 0.71 | 27.56 |
| 191 | 19.53 | 0.71 | 27.63 |

| Number of complex channels | Divide the measured mean of the rectified noise by this factor to derive the corrected standard deviation (symmetric normal distribution) of the noise. | Divide the measured standard deviation of the rectified noise by this factor to derive the corrected standard deviation (symmetric normal distribution) of the noise. | The ratio of (mean/stddev) correction factors. This can be a useful quality test of measured noise statistics. |
|---|---|---|---|
| 192 | 19.58 | 0.71 | 27.70 |
| 193 | 19.63 | 0.71 | 27.78 |
| 194 | 19.69 | 0.71 | 27.85 |
| 195 | 19.74 | 0.71 | 27.92 |
| 196 | 19.79 | 0.71 | 27.99 |
| 197 | 19.84 | 0.71 | 28.06 |
| 198 | 19.89 | 0.71 | 28.13 |
| 199 | 19.94 | 0.71 | 28.20 |
| 200 | 19.99 | 0.71 | 28.28 |
| 201 | 20.04 | 0.71 | 28.35 |
| 202 | 20.09 | 0.71 | 28.42 |
| 203 | 20.14 | 0.71 | 28.49 |
| 204 | 20.19 | 0.71 | 28.56 |
| 205 | 20.24 | 0.71 | 28.63 |
| 206 | 20.29 | 0.71 | 28.70 |
| 207 | 20.33 | 0.71 | 28.77 |
| 208 | 20.38 | 0.71 | 28.84 |
| 209 | 20.43 | 0.71 | 28.91 |
| 210 | 20.48 | 0.71 | 28.97 |
| 211 | 20.53 | 0.71 | 29.04 |
| 212 | 20.58 | 0.71 | 29.11 |
| 213 | 20.63 | 0.71 | 29.18 |
| 214 | 20.68 | 0.71 | 29.25 |
| 215 | 20.72 | 0.71 | 29.32 |
| 216 | 20.77 | 0.71 | 29.39 |
| 217 | 20.82 | 0.71 | 29.45 |
| 218 | 20.87 | 0.71 | 29.52 |
| 219 | 20.92 | 0.71 | 29.59 |
| 220 | 20.96 | 0.71 | 29.66 |
| 221 | 21.01 | 0.71 | 29.72 |
| 222 | 21.06 | 0.71 | 29.79 |
| 223 | 21.11 | 0.71 | 29.86 |
| 224 | 21.15 | 0.71 | 29.92 |
| 225 | 21.20 | 0.71 | 29.99 |
| 226 | 21.25 | 0.71 | 30.06 |
| 227 | 21.30 | 0.71 | 30.12 |
| 228 | 21.34 | 0.71 | 30.19 |
| 229 | 21.39 | 0.71 | 30.26 |
| 230 | 21.44 | 0.71 | 30.32 |
| 231 | 21.48 | 0.71 | 30.39 |
| 232 | 21.53 | 0.71 | 30.45 |

| Number of complex channels | Divide the measured mean of the rectified noise by this factor to derive the corrected standard deviation (symmetric normal distribution) of the noise. | Divide the measured standard deviation of the rectified noise by this factor to derive the corrected standard deviation (symmetric normal distribution) of the noise. | The ratio of (mean/stddev) correction factors. This can be a useful quality test of measured noise statistics. |
|---|---|---|---|
| 233 | 21.58 | 0.71 | 30.52 |
| 234 | 21.62 | 0.71 | 30.59 |
| 235 | 21.67 | 0.71 | 30.65 |
| 236 | 21.71 | 0.71 | 30.72 |
| 237 | 21.76 | 0.71 | 30.78 |
| 238 | 21.81 | 0.71 | 30.85 |
| 239 | 21.85 | 0.71 | 30.91 |
| 240 | 21.90 | 0.71 | 30.98 |
| 241 | 21.94 | 0.71 | 31.04 |
| 242 | 21.99 | 0.71 | 31.10 |
| 243 | 22.03 | 0.71 | 31.17 |
| 244 | 22.08 | 0.71 | 31.23 |
| 245 | 22.12 | 0.71 | 31.30 |
| 246 | 22.17 | 0.71 | 31.36 |
| 247 | 22.21 | 0.71 | 31.42 |
| 248 | 22.26 | 0.71 | 31.49 |
| 249 | 22.30 | 0.71 | 31.55 |
| 250 | 22.35 | 0.71 | 31.61 |
| 251 | 22.39 | 0.71 | 31.68 |
| 252 | 22.44 | 0.71 | 31.74 |
| 253 | 22.48 | 0.71 | 31.80 |
| 254 | 22.53 | 0.71 | 31.87 |
| 255 | 22.57 | 0.71 | 31.93 |
| 256 | 22.62 | 0.71 | 31.99 |

# Annex B
# CHANGES TO STANDARD

## CHANGES TO MS 9-2001 RESULTING IN MS 9-2008

### B.1.1 Summary

The definitions section has been clarified to better identify the regions where measurements are made and their relationships to the phantom and the coil. Specifically, it is broken up into four sections, one to define coil related definitions, one for analysis related definitions, the third for phantom related definitions and the fourth for image related definitions.

### B.1.2 Changes to introduction

- “Notice and Disclaimer” section added and expanded.
- Rationale section expanded and clarified.
- Scope section clarified to distinguish this standard from MS1, MS3 and MS6.

### B.1.3 Section 1

- Definitions organized according to subject matter: coils, analysis, phantoms and images.
- Definitions and their interrelatedness have been clarified.

### B.1.4 Section 2

- Image related definitions removed and placed into Section 1.
- Introduction added to ‘Selection of Measurement Geometry.’
- Subsequent procedures have been consolidated to reference MS1, MS3 or MS6 as appropriate.

### B.1.5 Section 3

- Rationalized the reporting requirements for SNR. Structured the required information into two sections: Geometric Information and Data Acquisition Parameters, followed by reporting of the SNR results. These are then carried over to the Uniformity section, as referenced sections from the SNR section, followed by reporting of Uniformity results.

### B.1.6 Annex A

Annex A added to highlight changes between versions of this standard.

## CHANGES TO MS 9-2008 RESULTING IN MS 9-2013

B.2.1 Section 2

- Add information related to noise statistics with more than 1 channel.

B.2.2 Annex A

- Add table with the channel count dependent noise statistics.

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