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STANDARDS PUBLICATION/NO. MS 6

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Characterization of Special Purpose Coils for Diagnostic Magnetic Resonance Images

NEMA

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION ■ 2101 L STREET, N.W., WASHINGTON, D.C. 20037

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NEMA MS 6-1991

MS 6

CHARACTERIZATION OF SPECIAL PURPOSE COILS FOR DIAGNOSTIC MAGNETIC RESONANCE IMAGES

Published by

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Preamble

This is one of a series of test standards developed by the medical diagnostic industry for the measurement of performance parameters governing the image quality of Magnetic Resonance Imaging 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 subdivision has identified a set of key magnetic resonance image quality parameters. This Standard describes the measurement of one of these parameters.

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 to be equivalent to the NEMA standard. The validity or equivalence of the modified procedure will be determined by each reader.

Uncertainty of the Measurements

The measurement uncertainty of the image quality parameter determined using this standard 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.

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Foreword

This Standards Publication is classified as NEMA Standard unless otherwise noted. It describes a method for evaluating special purpose radiofrequency coils for use with magnetic resonance (MR) imaging systems. These coils are used to receive signal from a limited portion of the anatomy. These include surface coils, flexible coils, pairs of coils such as Helmholtz coils, or coils which surround a specific tissue such as the knee or breast. Both receive-only and transmit-receive coils are included. The system head coil is excluded. These coils achieve good signal-to-noise performance because of their increased filling factor; in some cases, however, these coils have a nonuniform signal distribution.

The purpose of this procedure is to provide a standard means for measuring and reporting the signal-to-noise ratio (SNR) and nonuniformity of images acquired with special purpose 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 the proposed NEMA methods for determining the SNR and image uniformity of head and body coils. Evaluations are performed on images generated using standard clinical scan protocols.

This Standards Publication has been developed by the Magnetic Resonance Section 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:

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Rationale

Special purpose 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 define the volume near the coil which produces useful signal and to estimate the SNR at a reference point within that volume.

The increased signal-to-noise performance of some of these coils is accompanied by a loss of image uniformity. While image uniformity is generally a desirable goal, the loss of *undesired* signal can be exploited to reduce motion artifacts or to reduce image overfolding caused by undersampling when the field of view is small. Therefore, it is appropriate to map the sensitive volume of a special purpose coil, since a simple figure of merit for uniformity can be misleading.

The SNR is a sensitive, albeit rather non-specific, determinant 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. Since the sensitivity of many special purpose coils is spatially dependent, the former goal is achieved by measuring the SNR at a reference point relative to the coil position. Since different coils are designed for different coil-to-tissue distances, it is not possible to fix a single reference position which is meaningful for all. This reference point shall approximate the position of the anatomical feature for which the coil is used. This measurement procedure allows flexibility in the choice of reference position. It is understood that this flexibility can prevent direct comparison of different coil designs.

The loading of special purpose radiofrequency coils varies substantially from patient to patient and even from exam to exam for the same patient. Because of these variations, a loading scheme is not included in the 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. Loading of the phantom shall be considered when the specific hardware configuration makes the unloaded SNR less than optimally sensitive to system changes.

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Scope

This document defines test methods for measuring the signal-to-noise ratio and image nonuniformity of diagnostic magnetic resonance imaging systems using special purpose coils and performing proton imaging. These methods are applicable for both receive-only and transmit-receive coils. This document does not address the use of general head and body coils or spectroscopy.

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Section 1
DEFINITIONS

1.1 BASELINE PIXEL OFFSET VALUE

The baseline pixel offset value is the pixel value for a particular machine which represents a noise-free signal level of zero.

1.2 CHARACTERIZATION AREA

The characterization area is the intersection of the image plane and the characterization volume. This area includes the reference position.

1.3 CHARACTERIZATION VOLUME

The characterization volume is a regular geometric volume selected to demonstrate uniformity variations over the anatomical region for which the coil is used.

1.4 IMAGE ARTIFACT

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

1.5 IMAGE NONUNIFORMITY

Image nonuniformity is the variation of the pixel intensities in an image of a uniform phantom which are repeatable from scan to scan.

1.6 REFERENCE POSITION

The reference position is a point within the volume normally occupied by the anatomical feature for which the coil is used.

1.7 SENSITIVE VOLUME

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

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Section 2
METHODS OF MEASUREMENT

2.1 SELECTION OF MEASUREMENT GEOMETRY

2.1.1 Characterization Volume and Reference Position

Select a regular geometric volume (the characterization volume) to demonstrate uniformity variations over the anatomical region for which the coil is used. In the case of a multiple use coil, select one typical use. The characterization volume shall contain as much of the sensitive volume as practical. Consider the restrictions on phantom size (see 2.2.1 and 2.1.2) before selecting the characterization volume.

Select a reference position within the characterization volume. This a point in the region normally occupied by the anatomical feature for which the coil is used. Consider the restrictions on slice position (see 2.1.2 and 2.1.5) before selecting the reference position.

2.1.2 Characterization Area

The characterization area is the intersection of the image plane and the characterization volume and shall include the reference position. The test images in each plane shall include all of the characterization area.

2.1.3 Measurement Region of Interest (MROI)

The MROI is a 7 by 7 pixel square area of the image centered at the reference position. The mean value of this MROI shall be used as the numerator of the SNR. In addition, a preliminary calculation of the SNR within this region shall be used to select pixels for the noise calculation.

2.1.4 Noise Evaluation Area

Image noise shall be evaluated within a regular closed geometric area comprising the 49 pixels of the MROI plus at least 72 additional pixels. The shape of the noise evaluation area shall be chosen to ensure that at least 121 pixels have relatively high SNR (see 2.4 item 7). The simplest noise evaluation area would be the 11 by 11 pixel square area centered on the reference position (Figure 2-1), while certain coils require a more complex geometry to ensure that all of the pixels meet the SNR requirement (see, for example, Figure 2-2.)

2.1.5 Slice Positions

Nonuniformity measurements are performed in two orthogonal planes. SNR is evaluated from one of these planes. Both planes must pass through the reference position. Since the purpose of the measurement is to demonstrate the falloff of signal away from the coil structure, both planes shall pass through the coil structure. This also facilitates measurement of the distance between the coil and the reference position on the images. For most surface coils, the slice planes shall be orthogonal to the plane of the coil, and shall include the central axis of the coil (see Figure 2-3). For elliptical surface coils, one plane shall include the major axis of the ellipse and the other shall include the minor axis of the ellipse. For cylindrical coils, one plane shall be perpendicular to the cylinder axis. Coils shall be located as near to their normal operating position in the magnet as is practical. In all cases, the slice positions

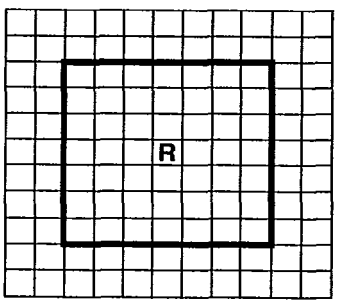
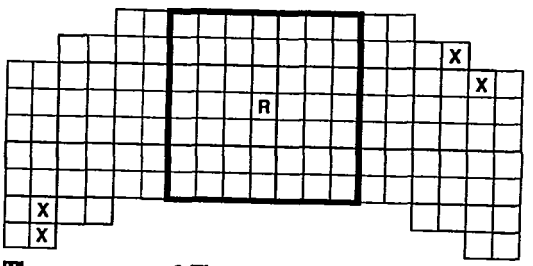


Figure 2-1 shows the simplest geometry for the noise evaluation area. An 11 by 11 pixel square is centered on the reference position R. The outlined 7 by 7 pixel square is the measurement region of interest. The noise evaluation area contains 121 pixels, the minimum required by this standard, so every pixel must meet the SNR criterion of 2.4 item 7.

Figure 2-1
SIMPLEST GEOMETRY OF NOISE EVALUATION AREA



The geometry of Figure 2-1 is not always suited to every coil type. Figure 2-2 shows a more complex geometry. The noise evaluation area consists of 133 pixels. In this example, some of the pixels do not meet the SNR requirement (X's). These pixels are not included in the standard deviation (noise) calculation. Since more than 121 pixels do meet the requirement, they provide a valid data set for noise evaluation.

Figure 2-2
A COMPLEX NOISE EVALUATION AREA

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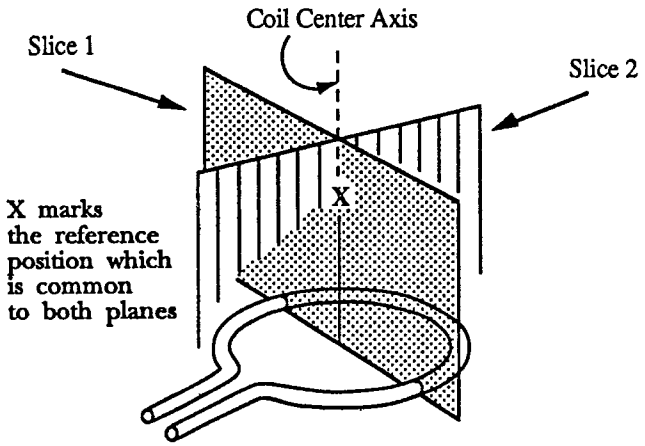


Figure 2-3
SLICE POSITIONS FOR A SURFACE COIL

shall be indicated on the drawing which accompanies the measurement result (see Section 3).

2.2 TEST HARDWARE

2.2.1 Test Volume

For each selected slice, the signal-producing volume of the phantom must enclose at least the entire volume defined by the slice thickness and the characterization area for that slice. The phantom or phantom position may be changed for the second slice position.

2.2.2 NMR Characteristics of the Signal Producing Volume

The following are NMR characteristics of the signal producing volume:

$T_1 < 1200$ milliseconds (at operating field strength)
$T_2 > 50$ milliseconds (at operating field strength)
Spin density = density of H_2O ± 20%

2.2.3 RF Coil Loading Characteristics

A loading scheme is not included in the standard. Since both loaded and unloaded SNR's are sensitive to changes in the remainder of the MR system, either shall be permitted in this measurement procedure. See description under "Rationale."

2.3 SCAN CONDITIONS

Imaging shall be performed using a typical clinical scan sequence. Images shall be reconstructed by a procedure which yields a pixel value which is proportional to the MR signal value from the corresponding voxel.

IMPORTANT: No algorithm which compensates for nonuniformity shall be employed. This requirement is not intended to exclude algorithms which combine the signals from multiple coils.

Some of the following steps involve statistical analysis of the images. This analysis must be performed on images which have been processed by the system's typical diagnostic clinical reconstruction algorithm, but prior to any further modification for display purposes (e.g., interpolation, filtering). All such user-selectable filters shall be disabled. If this is not possible, the filter employed shall be noted in the results (Section 3). The images to be analyzed shall be substantially free of image artifacts, other than image nonuniformity due to spatial variations in the sensitivity of the special purpose coil.

The field of view for each image must encompass the entire characterization area for the selected image plane.

In addition, the following scan conditions shall be used to acquire data:

1. Room and phantom temperature shall be 22 ± 4°C;
2. $TR \leq 5 \times T_1$ of filler material in signal producing volume;
3. TE within clinically selectable range;
4. Spin echo pulse sequence (first echo); and
5. Slice thickness ≤ 10mm.

2.4 MEASUREMENT PROCEDURE FOR SNR

Special purpose coil SNR is determined by sequentially executing the following procedure. The images recorded during this procedure can additionally be evaluated for nonuniformity.

1. Position the signal-producing volume relative to the special purpose coil as prescribed in 2.1.5 and 2.2.1. One of the two slice positions described in 2.1.5 is selected for the SNR measurement.
2. Perform the standard clinical pre-scan calibration procedure as recommended by the system manufacturer.
3. Execute two scans sequentially with less than 5 minutes elapsed time from the end of the first scan to the beginning of the second (images number 1 and 2). No system adjustment or calibration shall be performed between the scans.
4. Determine the mean pixel value within the MROI (as defined in 2.1.3) on image 1. The resulting number (minus any baseline pixel offset value) shall be called the image signal (S).
5. Calculate a pixel-by-pixel signed difference image (hereafter referred to as image 3) as follows:
   [image 3] = [image 1] - [image 2].
   Note that the image subtraction process must avoid errors which could result from the generation of pixel values which exceed the maximum/minimum pixel values allowed on the particular scanning system.
6. Calculate the standard deviation within the MROI of the subtracted image (image 3). This value is

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divided by the square root of two to give the preliminary image noise estimate (P).

7. Examine those pixels in image 1 which fall within the noise evaluation area 2.1.4 and reject any pixels that have intensity values less than 5 times P (adjusting for any baseline pixel offset). At least 121 pixels must remain. Otherwise, an imaging protocol having greater SNR must be chosen, or a larger noise evaluation area must be defined. The coordinates of these pixels are the valid noise pixels.

   In absolute value images, the noise in regions with significant signal has a Gaussian distribution, while the noise in non-signal-containing areas has a Rayleigh distribution. In order to make this procedure valid for both real and absolute value images, noise shall be evaluated only in those areas containing significant signal. This is accomplished by making a preliminary image noise estimate (see 2.4 item 6) based on the MROI, and then identifying in the original, unsubtracted image those pixels within the noise evaluation area that have intensities of at least five times the preliminary image noise estimate.

Authorized Engineering Information

8. Determine the standard deviation (SD) of the pixels in image 3 which have the coordinates of the valid noise pixels.
9. Calculate the SNR as follows:

$$SNR = \frac{S}{\left(\frac{SD}{\sqrt{2}}\right)}$$

2.5 MEASUREMENT PROCEDURE FOR IMAGE NONUNIFORMITY

Special purpose coil image nonuniformity is determined by sequentially executing the following procedure. It shall be permitted to evaluate for nonuniformity one of the two images recorded for the SNR measurement to reduce measurement time. Steps one through four are repeated for each of the two scan planes.

1. Position the signal-producing volume relative to the special purpose coil as prescribed in 2.1.5 and 2.2.1.
2. Perform the standard clinical pre-scan calibration procedure as recommended by the system manufacturer.
3. Perform the scan.
4. Image nonuniformity shall be determined by manipulation of the resulting image. A single gray level shall be assigned to all pixels having intensity values I such that:

   $S(1 - F) < I \leq S\ (1 + F)$

where

S is the mean pixel value within the MROI (as defined in 2.1.3) minus any baseline pixel offset value;

F is a fraction that specifies the width of a histogram bin; F has a fixed value of 0.1; and

the intensity values I have been corrected for baseline pixel offset, if any.

Pixels having intensities:

$S(1 + F) < I \leq S\ (1 + 2\ F)$

are assigned the next brighter gray level. This process is continued, with each gray level including pixels for which I is:

$S\ (1 + n\ F) < I \leq S\ (1 + (n + 1)\ F)$

$n = 1, 2, 3...$

until all pixels brighter than S have been assigned a gray level.

A similar procedure is applied to pixels with intensities less than S (1 - F). The gray level bins are defined by:

$S\ (1 - (n + 1)\ F) < I \leq S\ (1 - n\ F)$

$n = 1, 2, 3, ...9$

Pixels in the lowest intensity bin are assigned to black.

The resulting images shall be labeled to indicate physical dimensions.

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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 statement of the image SNR:

- Main magnetic field (B_o) direction;
- Position of the special purpose coil with respect to the gradient isocenter;
- Position of the characterization volume with respect to the coil structure;
- Size and shape of characterization volume;
- Position of the slice within the characterization volume;
- Position of the MROI within the characterization volume (this also defines the reference position); and,
- Size and shape of the noise evaluation area and its relationship to the MROI.

3.1.2 Data Acquisition Parameters

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

Parameter	Dimension
Phantom filler T_1	milliseconds
Phantom filler T_2	milliseconds
Pixel bandwidth	hertz per pixel
Voxel dimensions	millimeters
TR; sequence repetition time	milliseconds
TE; echo delay time	milliseconds
Number of signals averaged (NSA)	...
Data acquisition matrix size	...

A description of the coil loading if used shall be provided. If it was not possible to turn off all user-selectable filters (see 2.3), the filter which was used shall be noted. In addition, any other parameter required to ensure repeatability shall be reported.

3.1.3 SNR Results

The SNR value computed in 2.4 item 9 shall be provided.

3.2 REPORTING OF NONUNIFORMITY

3.2.1 Geometric Information

A dimensioned drawing (or drawings) showing all of the information described in 3.1.1 must accompany statement of the image nonuniformity. In addition, the drawing(s) shall indicate the position and the field of view of the manipulated image described in Section 2.5 item 4 relative to the special purpose coil.

3.2.2 Data Acquisition Parameters

The parameters listed in 3.1.2 must accompany the image nonuniformity results. In addition, the field of view of the manipulated image described in 2.5 item 4 shall be provided.

3.2.3 Nonuniformity Results

The manipulated image described in 2.5 item 4 shall be provided. This image shall be annotated to show the reference position and the dimension scale.

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The purpose of NEMA Standards, their classification and status are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below:

Purpose of Standards

National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

(Standardization Policies and Procedures, p. 1)

Definition of a Standard

A standard of the National Electrical Manufacturers Association defines a product, process or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 2)

Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the Standards Publication may be capable of otherwise equivalent performance.

(Standardization Policies and Procedures, p. 8)

Categories of Standards

National Electrical Manufacturers Association Standards are of three classes:

1. NEMA Standard, which relates to a product, process or procedure commercially standardized and subject to repetitive manufacture, which standard has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon;
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote thereon.
3. Adoptive Standard, which is adopted in whole or in part from the standards of another organization, either domestic, regional, or international.

(Standardization Policies and Procedures, pp 7 & 16)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote on the standard.

(Standardization Policies and Procedures, pp. 7 & 16)

Official Standards Proposal

An Official Standards Proposal is an official draft of a proposed standard which is formally recommended to an outside organization(s) for consideration, comment and/or approval, and which has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon. *(Standardization Policies and Procedures, pp 7 & 16)*

Identification of Status

Standards in NEMA Standards Publications are identified in the foreword or following each standard as "NEMA Standard" or "Suggested Standard for Future Design." These indicate the status of the standard. These words are followed by a date which indicates when the standard was adopted in its present form by the Association.

The material identified as "Authorized Engineering Information" and "Official Standards Proposal" is designated similarly.

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