STD·NEMA MS 4-ENGL 1998 ■ 6470247 0516581 T86 ■

NEMA STANDARDS PUBLICATION

MS 4

ACOUSTIC NOISE MEASUREMENT PROCEDURE FOR DIAGNOSING MAGNETIC RESONANCE IMAGING DEVICES

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

NEMA Standards Publication MS 4-1989

(Revision 1998)

Acoustic Noise Measurement Procedure
for Diagnostic Magnetic Resonance Imaging Devices

Published by:

National Electrical Manufacturers Association
1300 North 17th Street, Suite 1847
Rosslyn, VA 22209

© Copyright 1998 by the National Electrical Manufacturers Association. All rights including translation into other languages, reserved under the Universal Copyright Convention, the Berne Convention for the Protection of Literary and Artistic Works, and the International and Pan American Copyright Conventions.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

CONTENTS

Foreword iii

Section 1 GENERAL 1
Preamble 1
Introduction 2
Rationale 2
Scope 2
Referenced Standards 3
Definitions 3

Section 2 DATA ACQUISITION PARAMETERS 5
Maximum Gradient Acoustic Noise (MGAN) Method 5
Maximum Clinical Acoustic Noise (MCAN) Method 5

Section 3 METHODS OF MEASUREMENT 7
Test Hardware 7
Hardware Set-Up 7
MGAN Measurement 7
MCAN Measurement 8

Section 4 RESULTS 11

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS

Not for Resale

Foreword

Unless otherwise noted, this NEMA Standards Publication has been approved as a NEMA Standard. It describes the test conditions and parameters which ensure that worst case acoustic noise levels are measured. It determines the maximum sound pressure level that a particular magnet/gradient system combination produces when using pulsed waveforms. In the absence of specific guidelines for sound level exposure with MR imaging equipment, this procedure references the OSHA guidelines for acoustic noise exposure and the IEC standards for sound level meters.[1]

This Standards Publication was developed by the NEMA Magnetic Resonance Section, which periodically reviews it for any revisions necessary to keep it up to date with changes in technology. Comments or proposed revisions are welcome and should be submitted to:

Vice President, Engineering
National Electrical Manufacturers Association
1300 North 17th Street, Suite 1847
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 Magnetic Resonance Section was composed of the following members:

Bruker Medical, Inc.—Billerica, MA
Caprius—Wilmington, MA
Elscint MR, Inc.—Fort Collins, CO
Fonar Corporation—Melville, NY
GE Medical Systems, Inc.—Milwaukee, WI
Greatbatch Scientific—Clarence, NY
Hitachi Medical Systems America, Inc.—Twinsburg, OH
Medical Advances, Inc.—Milwaukee, WI
Philips Medical Systems, North America Company—Shelton, CT
Picker International—Highland Heights, OH
Siemens Medical Systems, Inc.—Iselin, NJ
Toshiba America MRI, Inc.—San Francisco, CA

[1] See Section 1.1.

Previous page is blank

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Section 1
GENERAL

1.1 PREAMBLE

This is one of a series of test standards developed by the medical diagnostic industry for the measurement of parameters governing the safety of Magnetic Resonance (MR) 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 which 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 shall be carried out using the normal clinical operating mode of the system. For example, standard calibration procedures and standard reconstruction processes shall be used. No modifications to alter test results shall be used unless otherwise specified in these standards.

The NEMA Technical Committee of the MR Section has identified a set of key magnetic resonance safety parameters. This standard describes the measurement of one of these parameters.

1.1.1 Equivalence

It is intended and expected that manufacturers or others who claim compliance with these NEMA standard test procedures for the determination of safety 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.

1.1.2 Uncertainty of the Measurements

The measurement uncertainty of the safety 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.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

1.2 INTRODUCTION

Current passing through a wire placed in a magnetic field will generate a force orthogonal to both the direction of the field and current. Acoustic noise in MR imaging is caused by motion of the gradient coils and attached structures when current is passed through the coils. When this happens, a pulsatile noise is audible to the patient.

The loudest noise that can be generated at a given static magnetic field strength will occur when pulsed waveforms, consisting of maximum amplitude and minimum rise time transitions, are applied simultaneously to all three gradient axes. This is not a likely condition for most clinical imaging sequences but is representative of a worst case and is defined as the Maximum Gradient Acoustic Noise (MGAN) of the system. For clinical imaging conditions, the worst case acoustic noise occurs with pulse sequences using high gradient current duty cycles and high gradient current amplitudes and is defined as the Maximum Clinical Acoustic Noise (MCAN) of the system.

To determine the worst case acoustic noise of a system, the MGAN is normally used as the measurement method and the MCAN may be used as an additional measurement. To characterize the clinical operation of the gradient wave required for MGAN (c.f. Figure 2-1), the MCAN must be used.

1.3 RATIONALE

The sound generated by an MR system usually consists of a series of repetitive impulses. The relevant safety parameters required to characterize such a noise are the peak impulse sound pressure level (L_{peak}) and the time integral of the A-weighted sound pressure level (L_{eq}). In MR applications, the peak impulse sound pressure level is dependent on the peak amplitude of the individual pulses while the time integral of the A-weighted sound pressure level is dependent on the continuous exposure to a series of such pulses. This document describes methods to measure the worst case L_{peak} and L_{eq} of an MR System.

1.4 SCOPE

This NEMA Standards Publication describes two measurement procedures: Maximum Gradient Acoustic Noise (MGAN) and Maximum Clinical Acoustic Noise (MCAN).

To measure the MGAN, a trapezoidal bipolar test waveform is applied simultaneously to the X, Y, and Z gradient axes. The waveform shall be defined by five variables (rise-time, fall-time, amplitude, on-time, and repetition time) and shall be generated using the standard pulse sequence generation software and hardware used by the manufacturer. The generation of the test waveform is subject to the manufacturer's pulse sequence design limitations (amplitude, rise-time, fall-time, and duty cycle). Within these design limitations, the rise and fall times of the test waveform shall be the minimum allowed, the amplitude shall be the maximum allowed, and the duty cycle (on time/repetition time) shall be the maximum. Further, eddy current compensation, also known as pre-emphasis, must be included since this is the mode in which the system is operated. The acoustic noise will be greater with pre-emphasis.

To measure the MCAN, the worst case clinical sequence is used. This is the sequence with the worst case combination (acoustically) of high gradient current duty cycle and gradient current amplitudes (e.g., short echo time, minimum repetition time, minimum slice thickness, minimum field of view, and oblique scan planes).

This procedure has been designed for measuring peak sound pressure levels (SPL) up to 140 dB. Above 140 dB, the use of more sophisticated equipment and methods may be required.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

1.5 REFERENCED STANDARDS

The following publications are adopted as indicated by reference in this Standards Publication. The mailing address of each referenced organization is also provided.

International Electrotechnical Commission
1, Rue de Varembe
Geneva, Switzerland

CEI/IEC 651-1979* -01*	*Sound level meters*
CEI/IEC 651-amend. 1-1993-09	*Amendment 1 Sound level meters*
CEI/IEC 601-2-33	*Medical electrical equipment Part 2: Particular requirements for the safety of magnetic resonance equipment for medical diagnosis*

Occupational Safety and Health Administration
Department of Labor
200 Constitution Avenue, N.W.
Washington, D.C. 20210

29CFR-1996, Part 1910.95	*Occupational Noise Exposure*

American National Standards Institute
11 West 42nd Street
New York, New York 10036

ANSI S1.4-1983	*Sound Level Meters*
ANSI S1.4a-1985	*Amendment to ANSI S1.4-1983*

1.6 DEFINITIONS

1.6.1 A-weighting

This refers to SPL frequency weighting. The ear does not respond uniformly to all frequencies. SPL measurements made with an A-weighting correspond to noise levels which are similar to those heard by the human ear (IEC 651).

1.6.2 Basic OSHA Standards

The OSHA limit for Lpeak (unweighted) is 200 pascals (or 140 dB referenced to 20 micropascals). The OSHA limit for Leq (A-weighted) for occupationally exposed individuals is 90 dBA averaged over 8 hours per 24 hour day (or 105 dBA over 1 hour). The OSHA Leq standard is intended for occupational exposure and is therefore highly conservative if applied to the infrequent exposures typically encountered in MR scanning. The International Electrotechnical Commission has adopted limits lower than OSHA in its MR Safety Standard (CEI/IEC 601-2-33).

---

* Available from ANSI, 11 West 42nd Street, New York, New York 10036.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

1.6.3 ISLM (Integrating Sound Level Meter)

The ISLM has the capability to compute the root-mean-square (rms) and the peak instantaneous value of time varying sound energy.

1.6.4 Leq

Leq is the rms SPL averaged over the measurement period.

1.6.5 Lpeak

Lpeak is the peak impulse SPL measured during the measurement period.

1.6.6 SPL (Sound Pressure Level)

The SPL is defined as ten times the common logarithm of the ratio of the square of the measured sound pressure to the square of the standard reference pressure of 20 micropascals.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS

Not for Resale

Section 2
DATA ACQUISITION PARAMETERS

2.1 MAXIMUM GRADIENT ACOUSTIC NOISE (MGAN) METHOD

The following parameters must be reported for the MGAN method per Section 4 (see Figure 2-1):

Parameter	Dimension
Bo (static field strength)	tesla
Gradient pulse amplitude (A+max A-max)	millitesla/meter
Rise and fall times (r1,r2,r3 and r4)	microseconds
Gradient pulse on-time (X)	milliseconds
Gradient pulse repetition time (TR)	milliseconds
Meter response time*	–

2.2 MAXIMUM CLINICAL ACOUSTIC NOISE (MCAN) METHOD

The following parameters must be reported for the MCAN Method per Section 4:

Parameter	Dimensions
Bo (static field strength)	tesla
Sequence type/name	–
Repetition time	milliseconds
Echo time(s)	milliseconds
# slices	–
Slice thickness	millimeters
Field of view	millimeters
Data acquisition matrix size	–
Scan plane	–
Meter response time *	–

* For short integration periods (10 seconds or less), the different responses of a FAST and SLOW network can produce slightly different levels of Leq; discrepancy will "average out" and disappear after 20 seconds of integration. It is recommended that a FAST neter response time (125 milliseconds time constant per IEC 651) be used for the measurement. However, a SLOW meter response time (1000 milliseconds time constant per IEC 651) can be used for integration periods greater than 20 seconds. (This note has been approved as Authorized Engineering Information.)

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

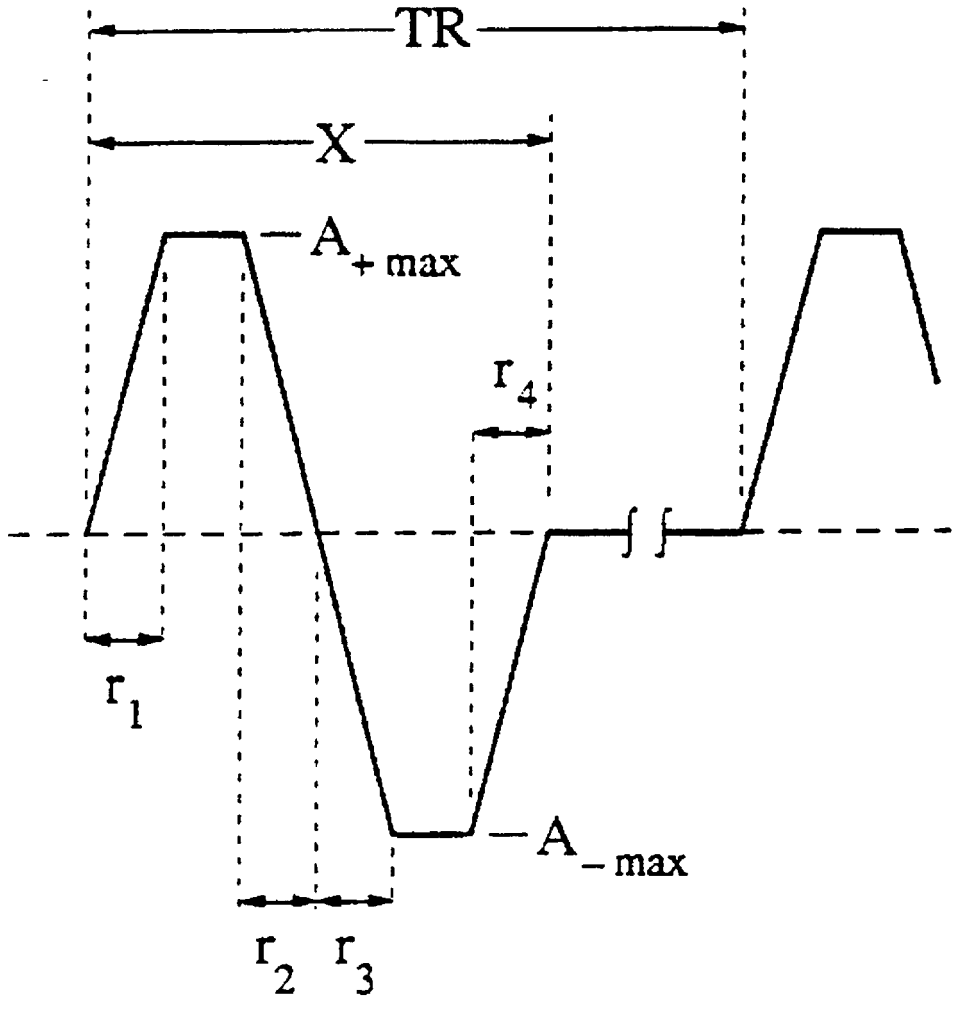


Figure 2-1
MAXIMUM AMPLITUDE BIPOLAR GRADIENT AMPLIFIER INPUT WAVEFORM (WITHOUT PRE-EMPHASIS)

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Section 3
METHODS OF MEASUREMENT

3.1 TEST HARDWARE

a. ISLM—An integrating sound level meter that meets ANSI Standard S1.4 Type 0 or 1 or IEC Standard 651 Type 0 or 1 is required.

b. Microphone—The microphone must be omnidirectional and insensitive to magnetic fields or calibrated to account for the magnetic field.

c. Extension cable—A microphone extension cable is required.

3.2 HARDWARE SETUP

a. The ISLM with the extension cable is calibrated using a sound level standard.

b. Make two measurements without a patient on the table. Both measurements shall be made with the microphone aimed in a direction orthogonal to the patient axis and in a horizontal plane. The first measurement shall be made at magnetic isocenter and the second measurement at the end of the patient bore (e.g., couch position).

c. Using the microphone extension cable, the ISLM is placed sufficiently far from the magnet isocenter to be in a fringe field of less than 10 gauss. Care must be taken to ensure that environmental effects (e.g., pulsed gradient fields, EMI, etc.) are compensated for or avoided.

3.3 MGAN MEASUREMENT

a. Set up the equipment as described in 3.2.

b. It is recommended that the RF amplifier be switched into the "off" position prior to the start of this procedure.

NOTE—The above sentence has been approved as Authorized Engineering Information.

c. Measure the ambient A-weighted Leq using the following ISLM settings:

1. detector – rms
2. time weighting – FAST or SLOW
3. frequency weighting – A-weighting
4. measurement period – $\geq$20 seconds

d. Begin simultaneous pulsing of the gradients using the maximum amplitude bipolar gradient waveform (Figure 2-1). The transition times—r1, r2, r3, and r4—shall be the minimum that the system is capable of generating. The amplitudes, A+max and A-max, shall be the maximum gradient strength that can be generated by the system under normal gradient operating conditions. The on-time of the pulse, X, shall be the minimum that will allow the current waveform to attain the maximum current demanded by the pulse. The repeat time, TR, shall be the shortest allowed by the system gradient duty cycle limits.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

e. Using the MAX HOLD function (or equivalent), measure the unweighted Lpeak using the following ISLM settings:

1. detector – peak
2. time weighting – N/A
3. frequency weighting – no weighting
4. measurement period – ≥20 seconds

f. Measure the A-weighted Leq using the following ISLM settings:

1. detector – rms
2. time weighting – FAST or SLOW
3. frequency weighting – A-weighting
4. measurement period – ≥20 seconds

g. For the A-weighted ambient, unweighted Lpeak, and A-weighted Leq, a measurement shall be made at each microphone location.

3.4 MCAN MEASUREMENT

a. Set up the equipment as described in 3.2.

b. It is recommended that the RF amplifier be switched into the "off" position prior to the start of this procedure. (This sentence has been approved as Authorized Engineering Information.)

c. Measure the ambient A-weighted Leq using the following ISLM settings:

1. detector – rms
2. time weighting – FAST or SLOW
3. frequency weighting – A-weighting
4. measurement period – ≥20 seconds

d. Select a protocol from each major sequence type and maximize the following parameters:

1. gradient current transitions per unit time (e.g., minimum TR, minimum TE, maximum number of slices)
2. gradient current amplitude (e.g., minimum slice thickness, minimum FOV, minimum rise-time)

e. Initiate the clinical sequence determined from step 4 above.

f. Using the MAX HOLD function (or equivalent), measure the unweighted Lpeak using the following ISLM settings:

1. detector – peak
2. time weighting – N/A
3. frequency weighting – no weighting
4. measurement period – sufficient to include the maximum peak SPL

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

g. Measure the A-weighted Leq using the following ISLM settings:

   1. detector – rms
   2. time weighting – FAST or SLOW
   3. frequency weighting – A-weighting
   4. measurement period – scan time*

h. Using other slice orientations (including oblique), repeat steps 4 through 7 as needed to obtain the worst case SPL.

i. If unsure of the effect of a given scan parameter on SPL, repeat steps 4 through 8 as required, selecting the extreme settings for the parameter in question.

j. For the A-weighted ambient, unweighted Lpeak, and A-weighted Leq, a measurement shall be made at each microphone location.

---

* The Leq acoustic noise measurement period must begin **after** the start of the MR scan and must end **prior** to scan completion. If the acoustic noise varies during the MR scan, then the measurement period must include the maximum SPL.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Section 4
RESULTS

4.1 REPORTING RESULTS

a. State method used (MGAN or MCAN).

b. State the measured values for Ambient (dBA), Lpeak (dB), and Leq (dBA) at both microphone locations.

c. State the measurement periods (seconds).

d. List data acquisition parameters of 2.1 or 2.2 as appropriate.

e. List other relevant scan parameters and meter settings required to ensure repeatability.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

STD.NEMA MS 4-ENGL 1998 ■ 6470247 0516595 570 ■



NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION • 1300 NORTH 17TH STREET • SUITE 1847 • ROSSLYN, VA 22209

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS

Not for Resale