

IEEE Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures

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**Standards Committee
of the
IEEE Electromagnetic Compatibility Society**

Approved 9 December 1997

IEEE Standards Board

Abstract: Uniform measurement procedures and techniques are provided for determining the effectiveness of electromagnetic shielding enclosures at frequencies from 9 kHz to 18 GHz (extendable to 50 Hz and 100 GHz, respectively) for enclosures having no dimension less than 2.0 m. The types of enclosures covered include, but are not limited to, single-shield or double-shield structures of various construction, such as bolted demountable, welded, or integral with a building; and made of materials such as steel plate, copper or aluminum sheet, screening, hardware cloth, metal foil, or shielding fabrics.

Keywords: electromagnetic shielding, screened rooms, shielded enclosures, shielded rooms, shielding, shielding effectiveness

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

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ISBN 1-55937-962-6

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Introduction

(This introduction is not part of IEEE Std 299-1997, IEEE Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures.)

This document provides a standard set of methods and procedures for determining the shielding effectiveness of shielding enclosures. The enclosures of concern include those used for testing groups of equipment, vehicles, computing systems, and smaller units whose electromagnetic emission and susceptibility require determination without disturbance from other sources. MIL-STD 285 was the common reference for many years, but the applicability of that document lessened with the advent of technological changes. Further, restructuring within U.S. Government policies and procedures has resulted in an emphasis on the use of commercial standards and the discontinuance of documents such as MIL-STD 285. The basic premise of MIL-STD 285 is still in position—the shield effect is to provide an insertion loss to outside influence. This standard offers testing based upon the performance specifications of the shield, rather than a fixed set of parameters that may not be applicable to the shield in question. Specific test procedures and frequency ranges are then selected as needed.

The detailed concepts and efforts of the previous working groups must be recognized and acknowledged. Edwin Bronaugh, James Klouda, and Richard Schulz have served as unifying factors, in that they contributed to the original document and subsequent revisions. Special mention must be made of the work done by Norman Wehling, William Croisant, Jr., and Frederick Eriksen in testing and evaluating key concepts in the low and resonant ranges. Acknowledgment must also be made of the efforts of Dr. Eriksen, who served as both Secretary and Technical Writer for most of the latter period of this working group's existence. All contributions by the members are gratefully acknowledged. The working group that developed this revision of the standard had the following membership:

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Contents

1.	Overview.....	1
1.1	Scope.....	1
1.2	Purpose.....	1
1.3	Application.....	1
2.	References.....	2
3.	Definitions.....	2
3.1	General terminology	2
3.2	Technical terminology	2
4.	Preliminary procedures	3
4.1	Background.....	3
4.2	Test plan.....	3
4.3	Calibration.....	3
4.4	Reference level and dynamic range (DR).....	3
4.5	Preliminary shield check procedures	4
5.	Detailed procedures	4
5.1	Background.....	4
5.2	Recommended standard measurement frequencies	5
5.3	Pass/fail requirements	6
5.4	Shielding effectiveness calculation.....	6
5.5	Preparation procedures.....	6
5.6	Low-frequency measurements (9 kHz to 20 MHz)	6
5.7	Resonant range measurements (20 MHz to 300 MHz).....	10
5.8	High-frequency measurements (300 MHz to 18 GHz).....	17
6.	Quality assurance technical report.....	23
6.1	Status letter.....	23
6.2	Full test report	23
ANNEXES		
A	(informative) Rationale	25
B	(informative) Mathematical formulas	30
C	(informative) Miscellaneous supporting information	33
D	(informative) Guidelines for the selection of measurement techniques	36
E	(informative) Preliminary measurements and repairs	38

IEEE Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures

1. Overview

1.1 Scope

This standard provides uniform measurement procedures for determining the effectiveness of electromagnetic (EM) shielding enclosures at frequencies from 9 kHz to 18 GHz (extendable down to 50 Hz and up to 100 GHz).

The owner of the shielding enclosure shall provide the frequencies at which the shield will be tested, and the shielding effectiveness limits for pass/fail. This standard suggests a range of test frequencies that would provide very high confidence in the effectiveness of the shield.

1.2 Purpose

The purpose of this standard is as follows:

- a) To provide a standard procedure for the measurement of the effectiveness of shielded enclosures, in a broad range of radio frequencies, including a minimum set of recommended frequencies;
- b) To provide identical procedures applicable to frequencies other than the standard set; and
- c) To provide an optional measurement technique to detect the nonlinear behavior of high-permeability ferromagnetic enclosures (see Annex C).

1.3 Application

The measurement procedures provided in this standard apply to any enclosure having a smallest linear dimension that is equal to or greater than 2.0 m. Separate methods, to be provided in the future, shall be used for enclosures with any dimension smaller than 2.0 m.

In the case of enclosures that are to be used in anechoic or semianechoic applications, this procedure shall apply prior to the installation of any radio frequency (RF) absorber materials.

2. References

This standard shall be used in conjunction with the following standards. When the following standards are superseded by an approved revision, the revision shall apply.

ANSI C63.2-1996, American Standard for Electromagnetic Noise and Field Strength Instrumentation, 10 kHz to 40 GHz—Specifications.¹

IEEE Std 100-1996, IEEE Standard Dictionary of Electrical and Electronic Terms, 6th ed.²

IEEE Std 291-1991, IEEE Standard Method for Measuring Electromagnetic Field Strength of Sinusoidal Continuous Waves, 30 Hz to 30 GHz (ANSI).

IEEE Std 473-1985 (Reaff 1997), IEEE Recommended Practice for an Electromagnetic Site Survey (10 kHz to 10 GHz) (ANSI).

IEEE C95.1-1991 (Reaff 1997), IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz (ANSI).

3. Definitions

3.1 General terminology

3.1.1 shall: The use of this verb in a direction means that the following actions or procedures are officially part of the standard.

3.1.2 should: The use of this verb in a direction means that the following actions or procedures are recommended but are not officially part of the standard.

3.2 Technical terminology

Unless defined below, all technical terms are defined in accordance with IEEE Std 100-1996³.

3.2.1 dynamic range (DR): The range of amplitudes over which the receive system operates linearly (see Annex B.6). The DR is numerically equal to the difference between the maximum and minimum signal amplitudes when both terms are expressed in decibels. For a shielding effectiveness (SE) measurement, the important portion of the DR is from the reference level to the noise floor. This is what should be verified during the DR validation step of the SE procedures defined in 4.4 of this standard, and represents the maximum SE measurable at that frequency with that particular equipment and settings.

3.2.2 local source: An emitter located close enough to a shielding enclosure for its electromagnetic energy to illuminate only a localized portion of a shielding face. The effect is assessed by choosing the poorest performance in the set of measured locations.

3.2.3 owner (shielded enclosure user or owner): The individual, corporation, or organization that intends to use the shield and that is the ultimate source of the shielding requirement.

¹ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

²IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

³Information on references can be found in Clause 2.

3.2.4 shielding effectiveness (SE): The ratio of the signal received (from a transmitter) without the shield, to the signal received inside the shield; the insertion loss when the shield is placed between the transmitting antenna and the receiving antenna (IEEE Std 100-1996).

3.2.5 shielding enclosure: A structure that protects its interior from the effect of an exterior electric or magnetic field, or conversely, protects the surrounding environment from the effect of an interior electric or magnetic field. A high-performance shielding enclosure is generally capable of reducing the effects of both electric and magnetic field strengths by one to seven orders of magnitude depending upon frequency. An enclosure is normally constructed of metal with provisions for continuous electrical contact between adjoining panels, including doors.

3.2.6 testing agency: The organization that actually performs the tests and records the data.

4. Preliminary procedures

4.1 Background

The detailed procedures required for the measurement of shielding effectiveness (SE) are defined in Clause 5. There are a number of steps (reference measurement, measurement of dynamic range) that must be taken before the SE is measured, however, and these are defined here.

Initial performance checks of the shield, prior to measurement data collection, are not required by this standard. Refer to Annex E for suggested procedures if desired.

4.2 Test plan

A test plan shall be prepared and shall be approved by the owner or owner's representative. Tests shall be performed in accordance with the approved test plan.

The test plan shall include, but not be limited to, actual test frequencies, test result pass/fail requirements, test locations, and a proposed equipment list. In addition, requirements for maintenance of a test log and an accepted procedure for making changes to the test plan that may arise during testing should be included.

4.3 Calibration

Any piece of equipment, whose operation directly affects the numerical value of the SE, shall be in calibration before any critical measurements are begun. Dates of latest calibration (traceable to a national standard) shall be provided and shall be within the calibration cycle of the equipment.

4.4 Reference level and dynamic range (DR)

A reference level shall be determined as described in the individual subclauses addressing the low-frequency (magnetic), resonant range, and high-frequency (plane wave) measurements. This determination may be made as frequently as required by changes in the test configuration. The reference level shall be remeasured at the conclusion of testing at each frequency. The tests since the prior reference level determination shall be repeated if the values have varied by more than ± 3 dB.

Each unique equipment configuration used to measure SE shall be demonstrated to have adequate DR. Determination of the DR shall consist of excitation of the receiving equipment with the associated transmitting equipment, and demonstration that the equipment remains calibrated (linear) for all levels of received

and transmitted signals that are actually experienced during the test. This demonstration shall be accomplished by varying the receiver input with a calibrated attenuator and observing an equal change, in decibels, in the receive system. This test shall be done at least once for each test frequency.

The DR shall be at least 6 dB greater than the SE to be measured. DR can most efficiently be determined during the reference measurement. Effects of surrounding structure (walls, buildings, etc.) shall be minimized.

4.5 Preliminary shield check procedures

See Annex E.

5. Detailed procedures

5.1 Background

This clause contains the detailed procedures for the SE measurements. This standard defines a test procedure but does not define the frequencies at which the measurements should be made, nor does it define the minimum SE that constitutes pass/fail. The owner shall define these frequencies and all pass/fail requirements.

However, as a guide for owners, this standard recommends frequencies that can be selected for testing their shield. Successful tests at these frequencies should provide very high confidence that a shield system provides the specified SE at all the frequencies from 9 kHz to 18 GHz.

The detailed procedures are divided into three ranges, denoted as low frequency, resonance, and high frequency. Separate and distinct procedures and equipment are required in each of these ranges.

WARNING

For all measurements undertaken as a part of this standard, care shall be taken to protect personnel from RF hazards (ANSI C95.1-1991). This standard also suggests that authorization for transmit operation be obtained from the appropriate regulatory agency prior to activation of any transmitter. See Annex C.3. Care shall also be taken to avoid interference with other electronic equipment operating in the vicinity.

5.2 Recommended standard measurement frequencies

Test frequencies shall be chosen by the owner. Recommended test frequencies are defined in Table 1.

Table 1—Standard measurement frequencies

Standard frequency	Antenna type	Clause procedure
Low range^a		
9–16 kHz	Small loop	5.6
140–160 kHz	↓	↓
14–16 MHz	↓	↓
Resonant range^a		
20–100 MHz	Biconical	5.7
100–300 MHz	Dipole	↓
High range^b		
0.3–0.6 GHz	Dipole	5.8
0.6–1.0 GHz	↓	↓
1.0–2.0 GHz	Horn	↓
2.0–4.0 GHz	↓	↓
4.0–8.0 GHz	↓	↓
8.0–18 GHz	↓	↓

^aActual test frequencies shall be according to the approved test plan.

^bA single frequency in each band is recommended, but actual test frequencies shall be according to the approved test plan.

The frequencies may be extended to lower and higher ranges. Table 2 contains recommended frequencies in the extended ranges.

Table 2—Recommended extended range measurement frequencies

Frequency range	Antenna type	Clause procedure
50–110 Hz	Small loop	5.6
0.9–1.1 kHz	↓	↓
35–45 GHz	Horn	5.8
90–100 GHz	↓	↓

5.3 Pass/fail requirements

Minimum acceptable pass/fail requirements shall be defined by the owner.

5.4 Shielding effectiveness calculation

Data obtained by the measurement procedures of the following subclauses are converted to shielding effectiveness by mathematical relationships defined in Table 3 and Annex B.

Table 3—Mathematical shielding relationships

Frequency range	Measured quantities	Units	Shielding effectiveness (dB)
Linear units			
9 kHz–20 MHz (extendable down to 50 Hz)	H_1, H_2	$\mu\text{A/m},$ μT	$S_H = 20 \log_{10} \frac{H_1}{H_2}$ (B.1) ^a
	V_1, V_2	μV	$S_H = 20 \log_{10} \frac{V_1}{V_2}$ (B.2)
20–300 MHz	E_1, E_2	$\mu\text{V/m}$	$S_E = 20 \log_{10} \frac{E_1}{E_2}$ (B.3)
1.7–18 GHz (extendable up to 100 GHz)	P_1, P_2	watts	$S_P = 10 \log_{10} \frac{P_1}{P_2}$ (B.4)
Logarithmic units			
All frequencies (as listed above)	All, in dB related values	dB	$SE = E_1 \text{ (dB)} - E_2 \text{ (dB)}$ (B.5a) $SE = H_1 \text{ (dB)} - H_2 \text{ (dB)}$ (B.5b) $SE = V_1 \text{ (dB)} - V_2 \text{ (dB)}$ (B.5c) $SE = P_1 \text{ (dB)} - P_2 \text{ (dB)}$ (B.5d)

^aSee Annex B.

5.5 Preparation procedures

Before detailed measurements are undertaken, the equipment shall be calibrated in accordance with 4.3, and reference levels and DR shall be determined in accordance with 4.4.

5.6 Low-frequency measurements (9 kHz to 20 MHz)

Standard low-frequency measurements utilize a small electrostatically shielded loop that, because of its size, enables evaluation of the performance of the enclosure when exposed to magnetic sources near the enclosure walls.

5.6.1 Frequency range and band

The small-loop method provides a standard test procedure for the 9 kHz to 20 MHz range. The three recommended frequencies for shielding measurements are a single frequency within the 9 to 16 kHz band, one

within the 140 to 160 kHz band, and another within the 14 to 16 MHz band. Actual test frequencies shall be selected by the owner.

These procedures are extendable down to 50 Hz. At lower frequencies it is anticipated that somewhat different equipment may be required to gain DR. For example, additional turns may be required on the receive and/or transmit loop antennas.

5.6.2 Equipment and setup

Signal sources, measuring equipment, and arrangement shall be in accordance with the following subclauses and Figure 1. All equipment shall have written proof of current calibration in accordance with 4.3.

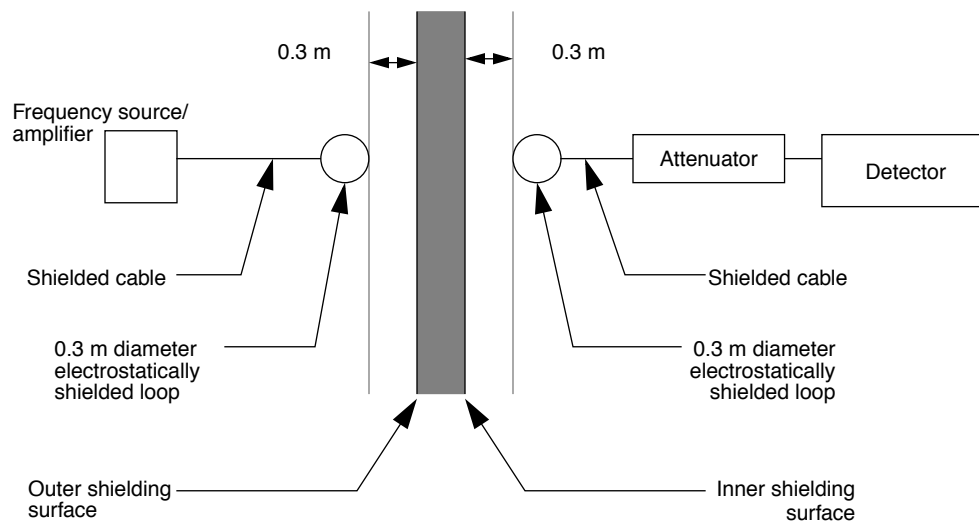


Figure 1—Schematic diagram of the test configuration for magnetic tests showing dimensions of transmit (TX) and receive (RX) antennas (Coplanar antenna orientations shown)

5.6.2.1 Source of magnetic field

The magnetic field shall be generated by a current in a 0.3 m diameter electrostatically shielded loop antenna. An ordinary audio frequency generator, plus amplifier, is usually adequate to supply the loop current if a suitable impedance matching device is used. Impedance matching may be needed to obtain the required DR.

5.6.2.2 Receive antenna

The receive antenna shall be a 0.3 m diameter electrostatically shielded loop connected to a field-strength meter, spectrum analyzer, or similar device.

5.6.3 Preliminary procedure

The nonlinear behavior of high-permeability ferromagnetic enclosures shall be considered before measuring shielding performance (see Annex C).

5.6.3.1 Shielding defects

Magnetic field testing specifically in the 14 MHz to 16 MHz range is strongly recommended because of good sensitivity to shielding defects in that range. Problem areas shall be identified.

5.6.4 Reference measurements

The reference field (H_1) produced by the source in the absence of the shielding enclosure shall be obtained by direct measurement with the receiving loop spaced from the transmitting loop by 0.6 m edge to edge (see Annex C.1) plus the thickness of the shielding barrier, which is the same total loop-to-loop distance that will be utilized when a shielding barrier intervenes. Both loop antennas shall be in the same plane (coplanar).

At this time, the adequacy of the DR shall be demonstrated in accordance with the procedures in 4.3.

5.6.5 Measurement procedure

The measurements shall be made in accordance with Figures 1 and 2, with the transmitting and receiving loops each spaced by 0.3 m from the respective shielding barrier and coplanar in a plane perpendicular to the wall, ceiling, or other surface being measured. At each frequency and location, the generator output shall be maintained at the value used during the reference measurement (see 5.6.4).

During all low-frequency measurements, one loop (typically the transmit loop) shall be maintained in a fixed position and the second loop (typically the receive loop) shall be reoriented and displaced (physically swept at least one-fourth the seam length on either side of the exact coplanar location) to seek a worst-case measurement; the maximum indication of the detector reading shall be used for determining the SE. Therefore, it is acceptable to position the external and internal loops only approximately coplanar when beginning the search for the worst-case measurement; however, the final measurement shall be made in the coplanar configuration.

5.6.5.1 Measurement locations

Around single-panel entry doors, small-loop tests shall be conducted for 14 loop positions, as indicated in Figures 2a) and 2b). The plane of the loop shall be perpendicular to the line of the door contact being tested. For the horizontal portion of the door seal, the loop shall be at the corners and equidistant from the edges. For the vertical contact regions, the loop centers shall be located at the corners and one-third the distance from both the top and the bottom. The top and bottom vertical contacts shall be measured as indicated in Figure 2b).

For multiple panel personnel or equipment entry doors, the above test positions apply to each door. See Figures 2b) and 2c).

For doors with dimensions exceeding 1.5 m $\times$ 2.5 m, additional test positions shall be added so that the spacing between test points does not exceed 1 m.

In the region of panel-to-panel seams, shielding enclosure construction is electrically nonuniform. Nonuniformities include regions where modular portions are joined together by a clamp or bolt assembly (or by staples for a foil-type shield), or by a soldered, brazed, or welded joint. Measurements shall be conducted in a similar manner to those around doors, except that the centers of the loops shall be located only at the midpoints of each seam or joint, whether horizontal or vertical, as in Figure 2d). In cases where the panel seams, whether bolted or welded, cannot be seen, attempts shall be made to determine the seam locations or panel sizes using applicable construction drawings or other documents. The test positions of Figure 2 shall be used for as much of the shield area as can be accessed for testing if the intervening nonshield materials are close enough to the shield to maintain the specified coupling distance between the loop antennas and shield proper.