

IEEE Standard Method for Measuring the Shielding Effectiveness of Enclosures and Boxes Having all Dimensions between 0.1 m and 2 m

IEEE Electromagnetic Compatibility Society

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Standards Development Committee

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IEEE Std 299.1™-2013

IEEE Standard Method for Measuring the Shielding Effectiveness of Enclosures and Boxes Having all Dimensions between 0.1 m and 2 m

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IEEE Electromagnetic Compatibility Society

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Abstract: This standard provides uniform measurement procedures for determining the shielding effectiveness of electromagnetic (EM) shielding for a variety of enclosures and boxes having all dimensions between 0.1 m and 2 m in the radio frequency range not addressed by IEEE Std 299™-2006. This standard is divided into two parts: Part I – 0.75 m to 2 m and Part II – physically small (< 0.75 m) but electrically large enclosures. In addition to a number of annexes aiding the measurement of shielding effectiveness of these enclosures, Annex I addresses physically small and electrically small enclosures, and Annex J addresses electrically small enclosures in reverberation chambers. Problems occurring in the testing of small enclosures having linear dimension less than 2 m are very different from determining the shielding effectiveness of large rooms and broad depending on the actual size of the enclosure itself. A number of other annexes are included that address rationale, mathematical formulas, selection of measurement techniques, preliminary measurement and repairs, wall-mounted monopoles, impedance mismatch correction, and using isolated monopoles in outer reverberation chambers.

Keywords: electrically large, electrically small, electromagnetic shielding, IEEE 299.1™, physically large, physically small, reverberation chamber, shielded enclosure, shielding effectiveness

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Introduction

This introduction is not part of IEEE Std 299.1™-2013, IEEE Standard Method for Measuring the Shielding Effectiveness of Enclosures and Boxes Having all Dimensions between 0.1 m and 2 m.

Enclosures and boxes constructed from various metals and other materials such as plastics coated with various metallic coatings are used to provide shielding against radiated emissions in various frequency ranges. Enclosures and boxes shall contain apertures to allow objects to pass through the shield to reach equipment inside the shield. A particular threat is represented by intended apertures whose radiation cannot be mitigated by electromagnetic gasketing. In particular, heat dissipation requirements fix a lower bound on aperture size. This is the reason why equipment-level enclosures typically offer a shielding effectiveness (SE) ranging from low to medium values.

The measurement of the SE of an enclosure is standardized in IEEE Std 299™-2006, IEEE Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures. While in the case of a large enclosure, the method does not show any particular problems, in the case of a small enclosure, some problems arise, especially in the definition of SE. IEEE Std 299-2006 does not address the measurement of the shielding effectiveness of enclosures having minimum linear dimension smaller than 2 m. IEEE Std 299-2006 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).

More precisely, a distinction is necessary between physically small but electrically large enclosures, and those that are both physically and electrically small. The former successfully allows a reverberation chamber (RC) method to be applied for SE evaluation by means of the frequency stirring technique in [B5]^a and [B23]. For the latter case, the traditional SE definition is hard to apply because of the undermoded condition, the strong dependence of the internal field on probe positioning and orientation, and the dependence on the incoming field polarization. For these reasons, an IEEE 299.1 Working Group was formed and engaged in effectively standardizing the case of small enclosures.

IEEE Std 299.1-2013, IEEE Standard Method for Measuring the Shielding Effectiveness of Enclosures and Boxes Having all Dimensions between 0.1 m and 2 m, is an extension of IEEE Std 299-2006. The purpose of IEEE Std 299.1-2013 is to provide test procedures for the measurement of the shielding effectiveness of enclosures whose maximum linear dimension is less than 2 m and whose minimum linear dimension is greater than 0.1 m. IEEE Std 299.1-2013 focuses on the test procedures for measuring the shielding effectiveness of small enclosures and boxes having linear dimensions between 0.1 m and 2 m at frequencies from 9 kHz to 18 GHz. This is a subclass of the enclosure not covered by the existing IEEE Std 299-2006; in fact, problems occurring in the testing of small enclosures, having linear dimension less than 2 m, are very different and broad depending on the actual size of the enclosure itself. Different sizes of small enclosures will be the scope of further standards on this subject.

^a The numbers in brackets correspond to those of the bibliography in Annex L.

Contents

1. Overview	1
1.1 Scope	2
1.2 Purpose	4
1.3 Application of test methods and use of this document	5
2. Normative references.....	6
3. Definitions	6
3.1 General terminology	6
3.2 Technical terminology	6
4. Preparing for shielding effectiveness measurements – preliminary procedures	8
4.1 Background.....	8
4.2 Test plan	8
4.3 Calibration	8
4.4 Reference level	8
4.5 Dynamic range (DR)	9
4.6 Personnel in shielded enclosure (tester and witness)	9
4.7 Preliminary shield check procedures	9
4.8 Reverberation qualification (7.2 and Annex J only).....	9
4.9 Pass/fail requirements.....	9
4.10 Usable frequency ranges and limits (7.2 only)	10
5. Measurement instrumentation	11
6. Measurement uncertainty	13
7. Test procedures.....	13
7.1 Part I – 0.75 m to 2 m enclosures	13
7.2 Part II – Physically small (< 0.75 m) and electrically large enclosures	30
8. Quality assurance technical report.....	38
8.1 Abbreviated test report	38
8.2 Full test report.....	38
Annex A (informative) Rationale (for Part I – 0.75 m to 2 m enclosures)	40
A.1 Basis.....	40
A.2 Considerations pertinent to the objectives of 1.2 of this standard	40
A.3 Cavity resonances	41
A.4 Measurement locations	44
A.5 Measurement equipment.....	45
Annex B (informative) Mathematical formulas (for Part I – 0.75 m to 2 m enclosures).....	46
B.1 Specific mathematical formulations.....	46
B.2 Low range (50 Hz to 20 MHz) shielding effectiveness.....	46
B.3 High range (300 MHz to 100 GHz) shielding effectiveness	47
B.4 Nonlinear (logarithmic) calculations.....	47
B.5 Dynamic range considerations	47
Annex C (informative) Miscellaneous supporting information (for Part I – 0.75 m to 2 m enclosures)	49
C.1 Coplanar versus coaxial loops.....	49

C.2 Nonlinearity of high-permeability ferromagnetic enclosures.....	49
C.3 Selecting measurement frequencies.....	49
Annex D (informative) Guidelines for the selection of measurement techniques (for Part I – 0.75 m to 2 m enclosures).....	52
D.1 Types of enclosures	52
D.2 Performance requirements	52
D.3 Equipment requirements.....	53
D.4 Regulatory agency conflicts.....	53
Annex E (informative) Preliminary measurements and repairs (for Part I – 0.75 m to 2 m enclosures).....	54
E.1 Background	54
E.2 Frequencies for preliminary check	54
E.3 Preliminary check procedures	54
Annex F (informative) Rationale for wall-mounted monopoles.....	56
Annex G (informative) Impedance mismatch correction	61
Annex H (informative) Using isolated monopoles in outer reverberation chamber	64
Annex I (informative) Measuring the shielding effectiveness of physically small and electrically small enclosures using magnetic field measurements (≤ 300 MHz)	66
I.1 Purpose.....	66
I.2 Rationale	67
I.3 Test setup and circuits	67
Annex J (informative) Electrically small enclosures in reverberation chambers	73
J.1 Background	73
J.2 Measurement procedure.....	74
J.3 Formula to be applied	75
J.4 Internal probe type and positioning.....	75
Annex K (informative) Utilization of absorbing (dissipative) materials in equipment enclosures for the measurement of shielding properties.....	76
Annex L (informative) Bibliography.....	83

IEEE Standard Method for Measuring the Shielding Effectiveness of Enclosures and Boxes Having all Dimensions between 0.1 m and 2 m

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1. Overview

IEEE Std 299.1TM-2013, IEEE Standard Method for Measuring the Shielding Effectiveness of Enclosures and Boxes Having all Dimensions between 0.1 m and 2 m, is an extension of IEEE Std 299TM-2006, IEEE Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures.¹ IEEE Std 299.1-2013 focuses on the test procedures for measuring the shielding effectiveness (SE) of small enclosures and boxes having linear dimensions between 0.1 m and 2 m. This is a subclass of the enclosure not covered by the existing IEEE Std 299-2006; in fact, problems occurring in the testing of small enclosures, having linear dimension less than 2 m, are very different and broad depending on the actual size of the enclosure itself. New definitions and test methods described in this standard can be applied to determine the shielding effectiveness for enclosures with apertures used in a variety of applications including power supplies, variable speed drives, and electronic equipment housings. A number of annexes are included that address rationale, mathematical formulas, selection of measurement techniques, preliminary measurement and repairs, wall-mounted monopoles, impedance mismatch correction, and using isolated monopoles in reverberation chambers. Other international standards, such as IEC 61000-5-7 on the protection provided by shielded enclosures, and IEC 61587-3 (Ed. 2) on the shielding performance of cabinets, racks, and subracks, are relevant to this standard, and those engaged in testing the shielding effectiveness of enclosures may want to refer to them.

¹ Information on normative references can be found in Clause 2.

1.1 Scope

This standard provides uniform measurement procedures for determining the effectiveness of electromagnetic (EM) shielding for a variety of physically small and large and electrically small and large enclosures within specified frequency ranges.

1.1.1 Document organization

To address each type of enclosure in one standard, Clause 7, Test procedures, is divided into two parts as described below. A number of annexes are included in this standard to provide supporting discussion on topics relevant to the subject of this standard. A brief description of the annexes is presented below.

Annex A includes considerations to constrain the effort and associated costs involved in the measurement (for 0.75 m to 2 m enclosures) method aimed to combine technical validity with a minimum of testing. Annex B includes the description of mathematical formulas and specific definitions for measures of enclosure performance for each associated measurement procedure. Annex C includes a miscellaneous supporting information for the 0.75 m to 2 m enclosures. Annex D describes the guidelines for the selection of measurement techniques for the 0.75 m to 2 m enclosures. Annex E contains recommendations for procedures to perform a cursory check (not required by the standard) on the shield for efficiency reasons in order to establish if the shield requires minor, and possibly major, repairs before the SE measurements are made. Annex F discusses the rational of using a wall-mounted monopole and shows how the power in an enclosure can be measured either in the center of the enclosure or at the wall of an enclosure. Annex G discusses in detail the rational for the mismatch correction discussed in 7.2.2. Annex H describes the use of isolated monopoles in outer reverberation chamber. Annex I addresses physically small and electrically small enclosures. Annex J addresses the testing of electrically small enclosures in reverberation chambers. Annex K addresses the utilization of absorbing (dissipative) materials in equipment enclosures for the measurement of shielding properties. Annex L includes the bibliographical entries that are cited in the text for this standard.

1.1.1.1 Clause 7, Test procedures, Part I – 0.75 m to 2 m enclosures

Part I of Clause 7 of this standard provides uniform measurement procedures for determining the effectiveness of EM shielding enclosures at frequencies from 9 kHz to 18 GHz (extendable 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 criteria. Part I of Clause 7 of this standard suggests a range of test frequencies that would provide very high confidence in the effectiveness of the shield. No attempt to define the results of testing enclosures is made in Part I of Clause 7 of this standard.

1.1.1.2 Clause 7, Test procedures, Part II – Physically small (< 0.75 m) and electrically large enclosures

Part II of Clause 7 of this standard addresses physically small, but electrically large enclosures. “Physically small” is defined as an enclosure less than 0.75 m on a side, and “electrically large” refers to an enclosure that supports several modes at the lowest frequency of interest, as discussed in 7.2. The procedure discussed in this part of the standard utilizes the reverberation chamber frequency-stirring technique presented in [B14]² and [B15]. 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. However, Part II of Clause 7 of this standard suggests a range of test frequencies that would provide very high confidence in the effectiveness of the shield. Part II of Clause 7 of this standard does not attempt to define what the SE results of enclosure testing should be.

² The numbers in brackets correspond to those of the bibliography in Annex L

1.1.1.3 Annex I (informative) – Measuring the shielding effectiveness of physically small and electrically small enclosures using magnetic field measurements (≤ 300 MHz)

This annex addresses the electromagnetic shielding of small enclosures, over the frequency range where they are electrically small. For the purposes of this standard, the physically small enclosures have dimensions that are in the range of 0.1 m to 0.75 m. Being electrically small means that the upper frequency for credible measurements shall be such that the wavelength is large compared to the largest dimension of the enclosure. Alternatively, the largest dimension of the enclosure shall be small compared to the wavelength. This requirement is satisfied if the following conditions are met by Equation (1) as:

$$\ell < \frac{\lambda}{10} \quad (1)$$

Where ℓ is the largest dimension of the enclosure and λ is the shortest wavelength that can be used for valid measurements. This is considerably smaller than the wavelength of the first resonance. These criteria can be converted to upper bound frequencies, since using Equation (2) as:

$$f = \frac{c}{\lambda} \text{ or } \lambda = c/f \quad (2)$$

Where c is the speed of light (approximately 3×10^8 m/s in air), this condition is equivalent to the expression given by Equation (3) as:

$$f < \frac{c}{10\ell} \quad (3)$$

This also means that the upper frequency, f , shall be less than 300 MHz for an enclosure whose longest interior dimension is equal to 0.1 m and less than 40 MHz for an enclosure whose longest dimension is shorter than 0.75 m. Note that these upper bound frequencies are considerably less than the half wavelength cavity resonance frequencies (1.5 GHz and 200 MHz respectively). Additional constraints on the upper frequency limit are imposed by the size and design of the test fixture and sensors.

Annex I of this standard only describes how to measure the magnetic field shielding effectiveness for the principal component, namely the component that is normal to the current flow. The non-principal components are assumed to be smaller. If other orientations are desired, the enclosure may be reoriented in the test fixture. Additional information relating to Annex I can be found in [B13] and [B4].

Although many standards seek to measure the magnetic and electric field shielding, this standard only measures the magnetic field shielding effectiveness. This is sometimes called the surface magnetic field attenuation. The assumption is made that the electrically small enclosure is made of conductive material having a surface resistance of less than a few ohms per square and a thickness of several skin depths. Under these conditions, an electric field cannot exist because it is shorted out by the enclosure walls.

1.1.1.4 Annex J (informative) – Electrically small enclosures in reverberation chambers

This annex addresses the measurement of shielding effectiveness of small enclosures. More precisely, a distinction is necessary between physically small but electrically large enclosures, and those that are both physically and electrically small. The former successfully allows a reverberation chamber (RC) method to be applied for SE evaluation by means of the frequency stirring technique in [B5] and [B9]. For the latter case, the traditional SE definition is hard to apply because of the undermoded condition, the strong dependence of the internal field on probe positioning and orientation, and the dependence on the incoming

field polarization. Alternative SE definitions are also therefore under investigation for such enclosures [B23]. The aim of Annex J is to begin describing this complex issue. In particular, the field coupling in a typical equipment-level enclosure is evaluated when it is placed inside an RC.

1.2 Purpose

The purpose of this standard is to provide test procedures for the measurement of the shielding effectiveness of enclosures whose maximum linear dimension is less than 2 m and whose minimum linear dimension is greater than 0.1 m.

1.2.1 General document organization

1.2.1.1 Clause 7, Test procedures, Part I – 0.75 m to 2 m enclosures

The purpose of Part I of Clause 7 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).

1.2.1.2 Clause 7, Test procedures, Part II – Physically small (< 0.75 m) and electrically large enclosures

The purpose of Part II of Clause 7 of this standard is as follows: a) to provide a standard procedure for the measurement of the effectiveness of shielded enclosures with all dimensions less than 0.75 m on a side for a minimum frequency range and higher. (The minimum frequency is defined as the frequency where several modes can be supported in the enclosure.); b) To provide identical procedures applicable for a large frequency range.

1.2.1.3 Annex I (informative) – Measuring the shielding effectiveness of physically small and electrically small enclosures using magnetic field measurements (≤ 300 MHz)

The purpose of Annex I is to describe how to measure the shielding effectiveness of physically small and electrically small enclosures over the frequency range where they are electrically small. Annex I describes how to measure the magnetic field shielding effectiveness for the principal component, namely the component that is normal to the current flow. The non-principal components are assumed to be smaller. If other orientations are desired, the enclosure may be reoriented in the test fixture.

1.2.1.4 Annex J (informative) – Electrically small enclosures in reverberation chambers

The purpose of Annex J is to effectively standardize the measurement of shielding effectiveness of small enclosures. A distinction is necessary between physically small but electrically large enclosures, and those that are both physically and electrically small. The former can be successfully tested for SE in an RC by means of the frequency stirring technique described in [B5] and [B9]. For the latter case, the traditional SE definition is hard to apply because of the undermoded condition, the strong dependence of the internal field on probe positioning and orientation, and the dependence on the incoming field polarization.

1.3 Application of test methods and use of this document

The measurement procedures provided in this standard depend on the physical and electrical dimensions of the enclosure under test. For Clause 7, Test procedures, Part I – 0.75 m to 2 m enclosures, the procedures apply to any enclosure having a smallest linear dimension between 0.75 m and 2 m. In addition, the enclosure shall be such that a person can enter and move an antenna around appropriately. For Clause 7, Test procedures, Part II – Physically small (< 0.75 m) and electrically large enclosures, the procedures apply to any enclosure having a largest linear dimension below 0.75 m and for a minimum frequency where several modes are supported in the enclosure. For Annex I, electromagnetic shielding of small enclosures is determined over the frequency range where the enclosure is electrically small. For the purposes of this standard, the small enclosures have dimensions that are in the range of 0.1 m to 0.75 m. Being electrically small means that the upper frequency for credible measurements shall be such that the wavelength is large compared to the largest dimension of the enclosure. Alternatively, the largest dimension of the enclosure shall be small compared to the wavelength. The upper frequency, f , shall be less than 300 MHz for an enclosure whose longest interior dimension is shorter than 0.1 m and less than 40 MHz for an enclosure whose longest dimension is shorter than 0.75 m. Note that these upper bound frequencies are considerably less than the half wavelength cavity resonance frequencies (1.5 GHz and 200 MHz respectively). Additional constraints on the upper frequency limit are imposed by the size and design of the test fixture and sensors. For Annex J, the field coupling in a typical equipment-level enclosure is evaluated when it is placed inside an RC.

This standard contains twelve annexes. Not all of the annexes provided here are for use with every part of this standard. The following describes the use of the annexes with the relevant part of this standard.

- a) Clause 7, Test procedures, Part I – 0.75 m to 2 m enclosures.
 - 1) Annex A (informative) – Rationale (for Part I – 0.75 m to 2 m enclosures)
 - 2) Annex B (informative) – Mathematical formulas (for Part I – 0.75 m to 2 m enclosures)
 - 3) Annex C (informative) – Miscellaneous supporting information (for Part I – 0.75 m to 2 m enclosures)
 - 4) Annex D (informative) – Guidelines for the selection of measurement techniques (for Part I – 0.75 m to 2 m enclosures)
 - 5) Annex E (informative) – Preliminary measurements and repairs (for Part I – 0.75 m to 2 m enclosures)
- b) Clause 7, Test procedures, Part II – Physically small (< 0.75 m) and electrically large enclosures.
 - 6) Annex F (informative) – Rationale for wall-mounted monopoles
 - 7) Annex G (informative) – Impedance mismatch correction
 - 8) Annex H (informative) – Using isolated monopoles in outer reverberation chamber
 - 9) Annex I and Annex J are provided to introduce the user to methods under further investigation.
- c) Annex I (informative) – Measuring the shielding effectiveness of physically small and electrically small enclosures using magnetic field measurements (≤ 300 MHz).
- d) Annex J (informative) – Electrically small enclosures in reverberation chambers.
- e) Annex K is provided to help users understand proper utilization of dissipative materials in enclosures when making shielding effectiveness measurements.
- f) Annex K (informative) – Utilization of absorbing (dissipative) materials in equipment enclosures for the measurement of its shielding properties.
- g) Annex L is provided as the bibliography for this standard.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they shall be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies. Another set of documents is listed in Annex L as references of engineering methodologies.

IEC 61000-4-21, Electromagnetic compatibility (EMC) — Part 4-21: Testing and measurement techniques – Reverberation chamber test methods. International Electrotechnical Commission (IEC), Geneva, Switzerland, (2011).³

IEC 61000-5-7, Electromagnetic compatibility (EMC) — Part 5-7: Installation and mitigation guidelines - Degrees of protection provided by enclosures against electromagnetic disturbances (EM code), (2001).

IEC 61587-3 Ed. 2, Mechanical structures for electronic equipment — Tests for IEC 60917 and IEC 60297 – Part 3: Electromagnetic shielding performance tests for cabinets and subracks, (2013).

IEEE Std C95.1™-2005, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.^{4, 5}

IEEE Std 299™-2006, IEEE Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures.

3. Definitions

For the purposes of this document, the following terms and definitions apply. *The IEEE Standards Dictionary: Glossary of Terms & Definitions* should be consulted for terms not defined in this clause.⁶

3.1 General terminology

shall: The use of this verb in a direction means that the following actions or procedures are mandatory to implement the standard.

should: The use of this verb in a direction means that the following actions or procedures are recommended to implement the standard.

3.2 Technical terminology

accessible test location: A test location that can be reached by a test antenna or probe without modifying a parent structure.

dynamic range (DR): The range of amplitudes over which the receive system operates linearly. For a measurement, the DR is the difference between the reference level and the minimum discernable signal

³ IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch/>). IEC publications are also available in the United States from the American National Standards Institute (<http://www.ansi.org/>).

⁴ IEEE publications are available from the Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

⁵ The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

⁶ IEEE Standards Dictionary Online subscription is available at:
http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

above the noise floor. The minimum discernable signal is defined as one with amplitude of 3 dB or more above the test system noise floor.

NOTE— This is what should be verified during the DR validation step of the SE procedures defined in 4.4 and 4.5 of this standard, and represents the maximum SE measurable at that frequency with that particular equipment and settings.⁷

electrically large: An enclosure that supports several modes at the lowest frequency of interest.

frequency stirring: A process applied to a shielded enclosure to facilitate the analysis in the high frequency range where a high mode density occurs.

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.

mode: A spatial field distribution inside an enclosure for a given enclosure size, shape, and for a given frequency. For a given enclosure size, there will be a finite allowable number of modes for a given frequency for the approach discussed in this standard to be valid.

mode stirring: The use of a mechanical stirrer(s) to vary the mode fields and excitations in order to generate a statistically uniform field in a reverberation chamber.

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.

parent structure: A permanent enclosure or outside housing that contains the shielding enclosure.

physically small: An enclosure less than 0.75 m on a side.

reverberation chamber: A metal enclosure large enough to support a large number of modes used to develop a statistical electromagnetic test environment. The statistical environment is generated with either mechanical and/or frequency stirring (Adapted from IEC 61000-4-21).

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.

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, vents, and other required openings.

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

⁷ Notes in standards are informative.

4. Preparing for shielding effectiveness measurements – preliminary procedures

There are a number of preparations that shall be made prior to measuring the shielding effectiveness of any shielded enclosure. The preparations described here apply to various parts of this standard. Detailed procedures required for the measurement of shielding effectiveness are discussed in Clause 7.

4.1 Background

Reading and following the preparations listed here in this clause prior to conducting shielding effectiveness measurements will help to ensure that correct measurement procedures are followed and that the shielding effectiveness data is accurate and repeatable. Examples of required preparations include reference measurement of the dynamic range of the measurement equipment. Verification of the dynamic range during the tests may be needed. However, preparations such as checking the initial performance of the shield prior to the collection of measurement data are not required by this standard. Annex E of this standard discusses additional preparations that may be carried out prior to measuring shielding effectiveness.

4.2 Test plan

A test plan shall be prepared. The plan shall be approved by the owner or owner's representative prior to the start of tests. 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 EMC measurement equipment (e.g., spectrum analyzer, antenna, etc.) that affects the numerical value of the shielding effectiveness shall be in calibration before any measurements are conducted. Equipment calibration certificates shall accompany the equipment, including calibration date and company performing the calibration, all traceable to a national calibration standard. No equipment affecting the numerical value of measured shielding effectiveness that is outside of the calibration date cycle shall be used to conduct shielding effectiveness measurements.

4.4 Reference level

As a part of the measurement process, a reference level shall be determined as described in the measurement procedures. The determination of reference level shall be made to assure that changes in the test setup do not affect the reference level resulting from changes in the test setup. The reference level shall also be re-measured at the conclusion of each test procedure when measurement frequency is often changed. If the measurement reference level verification varies from the initial reference level by more than ± 3 dB, then the test procedure shall be repeated, including reference level measurements.

4.5 Dynamic range (DR)

Each unique equipment configuration used to measure SE shall be demonstrated to have adequate dynamic range (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 external to the receiver and observing an equal change, in decibels, in the receive system. Alternatively, the internal input attenuator of the instrument can be used. In this case, linear operation is present if no change in signal amplitude is observed when changing the input attenuator setting. This test shall be done at least once for each test or each band of test frequency if an individual test contains more than one test band.

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.

4.6 Personnel in shielded enclosure (tester and witness)

It is not desirable to have personnel within the shielded room while testing the enclosure. If required, a maximum of two (2) people are allowed within the shielded room. This is intended to allow a tester and a witness.

4.7 Preliminary shield check procedures

Please see Annex E for a description of these procedures.

4.8 Reverberation qualification (7.2 and Annex J only)

The technique discussed in this standard requires the use of a reverberation chamber. There are processes in place for determining if a reverberation chamber meets a given performance guideline. This process is spelled out in IEC 61000-4-21. Thus, any reverberation chamber used in this test shall meet the minimum performance requirements given in IEC 61000-4-21. This requirement ensures that the outer reverberation chamber meets a field uniformity constraint in order to attain independent samples for the averaging procedure used in obtaining the SE as defined in Equation (8).

In this procedure, the outer reverberation chamber should meet performance requirements and/or criteria as defined in IEC 61000-4-21. This requirement ensures that the outer reverberation chamber meets a field uniformity constraint in order to attain independent samples for the averaging procedure used in obtaining the SE as defined in Equation (8).

4.9 Pass/fail requirements

The minimum acceptable pass/fail requirements for shielded effectiveness testing shall be defined by the owner.

4.10 Usable frequency ranges and limits (7.2 only)

Test frequencies shall be chosen by the owner. However, there is a minimum frequency limit in this measurement procedure for 7.2 of this standard. In order for the frequency stirring approach to be valid, the enclosure shall be able to support at least 60 modes for a given enclosure size and frequency. Thus, the minimum frequency that this procedure can be used for is a given enclosure size is given by Equation (4):

$$f_{\min} = c \left(\frac{90}{4\pi V} \right)^{1/3} \quad (4)$$

where V is the volume of the small enclosure in cubic m, and c the speed of light in m/s in air. Figure 1 plots this function for volumes as large as 1 m³.

While there is a minimum frequency requirement in this measurement procedure, there is no upper frequency requirement. However, the upper frequency may be governed by the test equipment used such as the VNA, cables, and antennas.

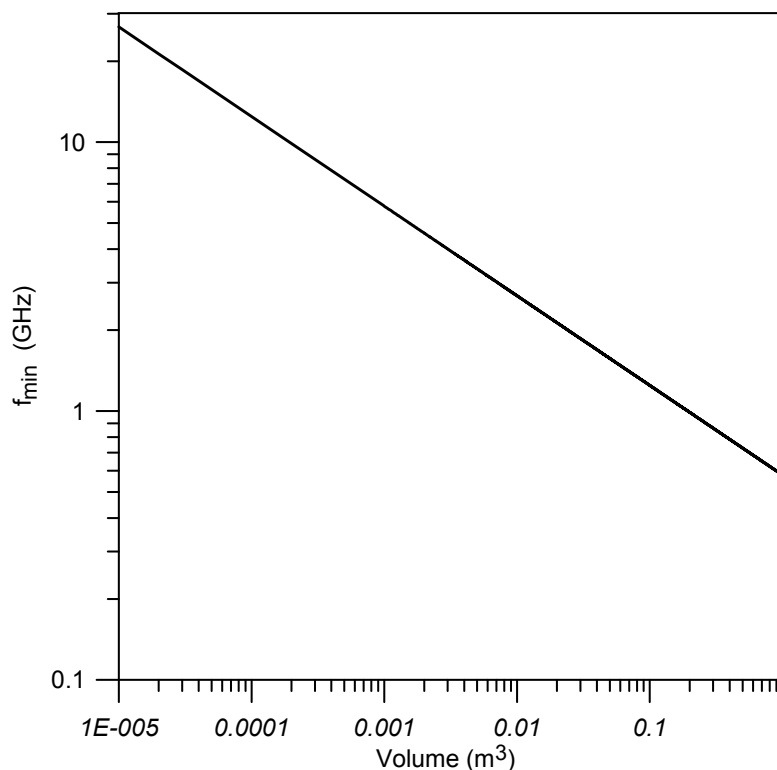


Figure 1—Minimum frequency versus enclosure volume

5. Measurement instrumentation

Various types of generation, matching, and measurement equipment used in electromagnetic compatibility work are required to perform measurements of shielding effectiveness. Table 1, Table 2, Table 3, Table 4, and Table 5 describe this equipment for each part of the test procedure.

**Table 1—Measurement instrumentation for shielding effectiveness measurements for
Part I: Low-frequency small-loop method**

Test Procedure Part of This Standard	Type of Equipment	Description of Equipment
Part I – 0.75 m to 2 m enclosures: Low-frequency small-loop method	Electromagnetically shielded loop antenna, quantity of two	0.3 m loop antenna that is electromagnetically shielded against electric fields used to generate the source of magnetic field; the other antenna is used as the receiving antenna.
	Audio frequency generator	Frequency generator that provides the signal in the audio frequency range for the audio frequency amplifier.
	Audio frequency amplifier	Amplifier that provides the current to the antenna.
	Impedance matching device	Device that matches the impedance between the amplifier and antenna.
	Field-strength meter	Device that measures the strength of the field generated by the antenna.
	Spectrum analyzer	Device that can be used to measure the field strength when fed from a calibrated antenna.

**Table 2—Measurement instrumentation for shielding effectiveness measurements for
Part I: High-frequency (non-resonant) method**

Test Procedure Part of This Standard	Type of Equipment	Description of Equipment
Part I – 0.75 m to 2 m enclosures: High-frequency non-resonant method	Antennas	Dipoles, biconical antennas, horns, yagis, log periodic, or other linear antenna types that can generate a continuous wave (CW) field.
	Field-strength meter	Device that measures the strength of the field generated by the antenna.
	Spectrum analyzer	Device that can be used to measure the field strength when fed from a calibrated antenna.

Table 3—Measurement instrumentation for shielding effectiveness measurements for Part II

Test Procedure Part of This Standard	Type of Equipment	Description of Equipment
Part II – Physically small and electrically large enclosures	Antennas	Monopoles, dipoles, horn antennas, or other linear antenna types that can generate a CW field and can fit properly the small enclosure.
	Coaxial cables	Two conductor (center conductor, shield system), concentric, constant-impedance transmission line; doubly-shielded coaxial cables should be used.
	Vector network analyzer	Device that measures both amplitude and phase properties of electrical networks.

Table 4—Measurement instrumentation for shielding effectiveness measurements for Annex I

Test Procedure Part of This Standard	Type of Equipment	Description of Equipment
Annex I – Physically small and electrically small enclosures	Strip-line test fixture	A test fixture consisting of two parallel plates consisting of a strip line circuit.
	Radio frequency (RF) power amplifier	Power amplification device that amplifies a (radio) high-frequency signal to a higher power level.
	Vector network analyzer	Device that measures both amplitude and phase properties of electrical networks.
	RF signal source	A signal generator that generates a radio-frequency signal of varying amplitude and frequency.
	RF power attenuators	Attenuators designed to absorb radio-frequency power at specific levels.
	Loop sensors	A loop used alone to produce an alternating current (AC) magnetic field to test Equipment Under Test (EUT) for susceptibility (immunity) to magnetic fields in a low frequency range typically from 30 Hz to 100 kHz.
	Surface probes	Small inductively coupled sensors designed to measure the RF current flowing in a particular direction on a conducting surface.

**Table 5—Measurement instrumentation for shielding effectiveness
measurements for Annex J**

Test Procedure Part of This Standard	Type of Equipment	Description of Equipment
Annex J – Electrically small enclosures in reverberation chambers	Antennas	Electric monopole.
	RF power amplifier	Power amplification device that amplifies a (radio) high-frequency signal to a higher power level.
	Vector network analyzer	Device that measures both amplitude and phase properties of electrical networks.
	Coaxial cables	Two conductor (center conductor, shield system), concentric, constant-impedance transmission line; doubly-shielded coaxial cables should be used.

6. Measurement uncertainty

Measurement uncertainty is a parameter that can be associated with the result of a measurement of shielding effectiveness. It characterizes the dispersion of values that could reasonably be attributed to the measurements. There are many aspects of SE where measurement uncertainty can be estimated to gain the overall expanded measurement uncertainty of the SE process contained in this standard. These include the uncertainties caused by the measurement instrumentation chain itself, the positioning of the transmit and receive antennas, the radio frequency (RF) loading of the room, and its effect on the room Q value, caused by the test personnel in the room, etc. Work is proceeding in addressing these uncertainty components. However, for the present and until this work is concluded, uncertainty is not required in the measurement of SE. It is recommended that a measurement uncertainty analysis be performed on each set of measurements and discussed in the final report. Clause 1 and Clause 2 list several references that can be used.

7. Test procedures

The test procedures for defining and determining the shielding effectiveness of various sizes of shielded enclosures with dimensions between 0.1 m and 2 m are provided and discussed below.

7.1 Part I – 0.75 m to 2 m enclosures

7.1.1 Background

This section contains the detailed procedures for the SE measurements for enclosures with dimensions 0.75 m to 2 m. This part of the standard defines a test procedure but does not define the frequencies at which the measurements should be made. This standard also does not define the minimum SE that constitutes a pass/fail criterion. 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 conducted at these frequencies should provide very high confidence that a shield system provides the specified SE at all the frequencies covered by this standard.

WARNING

For all measurements undertaken as a part of this standard, care shall be taken to protect personnel from potentially hazardous RF field levels (IEEE Std C95.1-2005). This standard also suggests that authorization for transmit operation be obtained from the appropriate regulatory agency prior to activation of any transmitter. See C.2. Care shall also be taken to avoid interference with other electronic equipment operating in the vicinity.

7.1.2 Recommended measurement frequencies

Test frequencies shall be chosen by the owner. Recommended test frequencies are defined in Table 6. The frequency range from 20 MHz to 300 MHz is not included in Table 6, because this is the frequency range around resonance.

Table 6—Standard measurement frequencies

Frequency	Antenna Type	Procedure in this Standard
Low Range ⁸		
9 kHz to 16 MHz	Small loop	7.1.5
16 MHz to 20 MHz	Small loop	7.1.5
High Range ⁹		
0.3 GHz to 0.6 GHz	Dipole	7.1.7
0.6 GHz to 1.0 GHz	Dipole	7.1.7
1.0 GHz to 2.0 GHz	Horn	7.1.7
2.0 GHz to 4.0 GHz	Horn	7.1.7
4.0 GHz to 8.0 GHz	Horn	7.1.7
8.0 GHz to 18 GHz	Horn	7.1.7

The frequencies may be extended to higher ranges. Table 7 contains recommended frequencies in the extended ranges. The frequency ranges in Table 7 were based on IEEE Std 299-2006 where measurement ranges are given. Not all frequency ranges are covered in IEEE Std 299-2006 or in Table 7 of this standard. Further research is needed to address frequency ranges not covered in Table 7.

Table 7—Recommended extended range measurement frequencies

Frequency Range	Antenna Type	Procedure in this Standard
35 GHz to 45 GHz	Horn	7.1.7
90 GHz to 100 GHz	Horn	7.1.7

7.1.3 Shielding effectiveness calculation

Data obtained by the measurement procedures of the following sections are converted to shielding effectiveness by mathematical relationships defined in Table 8 and Annex B. The magnitudes of the

⁸ Actual test frequencies shall be according to the approved test plan.

⁹ A full size dipole may not fit in the shield under test.

quantities E_1 , E_2 , H_1 , and H_2 are the field values measured using the antennas placed in the prescribed configuration.

Table 8—Mathematical shielded relationships¹⁰

Frequency range	Measured quantities	Units	Shielding effectiveness (dB)
Linear units			
9 kHz to 20 MHz (extendable down to 50 Hz)	$ H_1 , H_2 $	$\mu\text{A/m}$,	$SE_H = 20 \log_{10} \frac{ H_1 }{ H_2 }$
	$ V_1 , V_2 $	μV	$SE_V = 20 \log_{10} \frac{ V_1 }{ V_2 }$
300 MHz to 1.7 GHz, and 1.7 GHz to 18 GHz (extendable up to 100 GHz)	P_1, P_2	watts	$SE_P = 10 \log_{10} \frac{ P_1 }{ P_2 }$
Logarithmic units			
All frequencies (as listed above)	All, in dB related values	dB	$SE = E_1 \text{ (dB)} - E_2 \text{ (dB)}$ $SE = H_1 \text{ (dB)} - H_2 \text{ (dB)}$ $SE = V_1 \text{ (dB)} - V_2 \text{ (dB)}$ $SE = P_1 \text{ (dB)} - P_2 \text{ (dB)}$

7.1.4 Preparation procedures

Before detailed measurements are undertaken, the equipment shall be calibrated in accordance with 4.3, and reference levels and dynamic range shall be determined in accordance with 4.4 and 4.5, respectively.

7.1.5 Small-loop method – 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.

7.1.5.1 Small-loop frequency range and band

The small-loop method provides a standard test procedure for the 9 kHz to 20 MHz range. It is recommended that the shielding be measured at a minimum of one frequency in each of the following bands: 9 kHz to 16 kHz, 140 kHz to 160 kHz, and 14 MHz to 16 MHz. Actual test frequencies shall be selected by the owner.

¹⁰ See Annex B.

These procedures are extendable down to 50 Hz provided the loop will fit inside the enclosure. At lower frequencies, it is anticipated that somewhat different equipment may be required to gain adequate dynamic range. For example, additional turns may be required on the receiver loop and/or transmit loop antennas or more power may be required depending on the SE of the enclosure.

7.1.5.2 Equipment and setup

Signal sources, measuring equipment, and arrangement shall be in accordance with the following sub sections and Figure 2. For smaller enclosures, it may be necessary to place the receiving antenna closer to the enclosure wall than 0.3 m. The 0.3-meter dimension was selected to provide coordination with this requirement in IEEE Std 299-2006 regarding test equipment. All equipment shall have written proof of current calibration in accordance with 4.3.

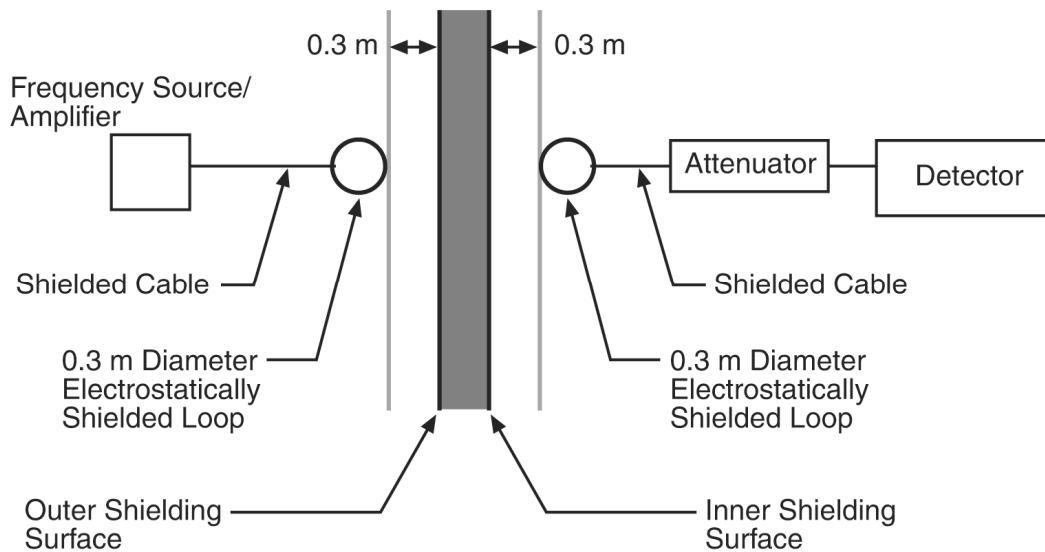


Figure 2—Dimensions of transmit (TX) and receive (RX) antennas
(Source: IEEE Std 299-2006)

7.1.5.2.1 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 dynamic range. A continuous wave (CW) signal without modulation shall be used to drive the antenna.

7.1.5.2.2 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. For smaller enclosures, a smaller receiving loop may be required, as the maximum size of the loop diameter should not exceed one-third of the related dimension of the enclosure. In these cases, the loop should be positioned in the center of the enclosure.

7.1.5.2.3 High-permeability ferromagnetic enclosures

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

7.1.5.2.4 Shielding defects

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

7.1.5.3 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, or the same spacing to be used during the test if the receiving loop shall be placed closer than 0.3 m (see Annex D) plus the thickness of the shielding barrier, which is the total loop-to-loop distance that will be utilized when a shielding barrier interns. Both loop antennas shall be in the same plane (coplanar).

7.1.5.4 Measurement procedure

The measurements shall be made in accordance with Figure 3, Figure 4, Figure 5, Figure 6, Figure 7, and Figure 8, 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. When testing the intersection of two surfaces, the antenna shall be orthogonal to both surfaces, as illustrated in Figure 7, and Figure 8. At each frequency and location, the generator output, which can be volts, watts, or a reference setting, shall be maintained at the value used during the reference measurement (see 7.1.5.3).

During all low-frequency measurements, one loop (typically the transmit loop) shall be maintained in a fixed position. The second loop (typically the receive loop) shall be reoriented the same as the transmission loop and displaced (physically swept laterally 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.

7.1.5.5 Measurement locations

Around single-panel entry doors, small-loop tests shall be conducted for 14 loop positions, as indicated in Figure 3 and Figure 4, where H_d is the longest dimension. For enclosures where the longest dimension is 1 m or less, it is only necessary to make three measurements on each side. 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 at one-third the distance from both the top and the bottom. The top and bottom vertical contacts shall be measured as indicated in Figure 4. In Figure 4, an enclosure door is depicted to show relative positions. This door can be on the floor or on the top of the enclosure.