



IEEE Guide for the Electromagnetic Characterization of Conductive Gaskets in the Frequency Range of DC to 18 GHz

IEEE Electromagnetic Compatibility Society

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**Standards Development Committee
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Abstract: Information to assist users of gaskets in evaluating gasket measurement techniques to determine which exhibit the properties critical to the intended application, to highlight limitations and sources of error of the competing measurement techniques, and to provide a basis for comparing the techniques is provided in this guide. Emphasis is placed on those measurement techniques that have been adopted through incorporation into standards, both commercial and military, or that have been used extensively.

Keywords: aperture transmission, electromagnetic shielding, EMI gaskets, measurement techniques, reverberation chamber, shielding effectiveness, stirred mode, transfer impedance

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Introduction

This introduction is not part of IEEE Std 1302-2008, IEEE Guide for the Electromagnetic Characterization of Conductive Gaskets in the Frequency Range of DC to 18 GHz.

An EMI gasket is a conductive material used to improve the electrical bonding between metallic parts of an electronic chassis, equipment enclosure, or electromagnetic shield. A wide variety of materials and techniques is used to produce EMI gaskets. The effectiveness of gaskets in the closing of seams and joints is dependent upon the properties of the gasket and the method of installation. Several techniques are available to measure the electromagnetic properties of EMI gaskets. Unfortunately, measurement results are often inconsistent between techniques.

This guide provides guidance on the use of recognized techniques for the electromagnetic performance characterization of EMI gaskets. It does not recommend one technique over another. It is recognized that some or all of the “alternative” techniques may, at some time in the future, become widely accepted and practiced. At such time, the guide will be revised to reflect their adoption. It is also recognized that efforts are currently underway to revise the measurement techniques currently covered in this guide. These revisions will be included in future updates of this document.

The theory of gasket behavior given in this guide is highly simplified and is intended to illustrate primary principles only. For a greater understanding of the electromagnetic interactions occurring in a gasketed joint, the reader is advised to consult the many excellent mathematical treatments in books and papers available through the IEEE and other technical publishers.

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1. Overview

1.1 Background

The ideal electromagnetic shield is an infinitely conductive enclosure with no apertures or penetrations of any kind. Functional requirements and practicalities of design and construction prevent this ideal from being realized. Penetrations for power, signals, and ventilation must be provided. Access apertures for calibrations, controls, and adjustments must exist. The different pieces of chassis and enclosure must be joined for the final product.

Electromagnetic energy exits or enters the shield at apertures, along conductive penetrations, and through imperfect seams. To restrict this coupling of energy to levels sufficiently low to comply with regulations and to permit interference-free operation, these unwanted coupling paths must be closed. Filters are used on the penetrations; screens and covers may be used over apertures. Seams and joints require special attention, however. For shielding, metal flow processes such as welding, brazing, and soldering are the preferred methods for making joints and seams. Many situations arise, however, where these techniques cannot be used and direct metal-to-metal contact does not provide an adequate electromagnetic seal. In these cases, an electromagnetic interference (EMI) gasket should be installed in the joint.

EMI gaskets are conductive materials designed to conform to joint surfaces and provide a low-impedance path. EMI gaskets are made from a wide variety of materials: beryllium copper, galvanized steel, stainless

steel, electroplated steel, aluminum, and conductively loaded polymers. Gasket types include spring fingers, spiraled bands, perforated sheets, knitted wire mesh, conductive fabric, reinforced foil, and oriented wires. Materials added to polymeric binders to achieve conductivity include copper, silver, carbon, aluminum, and nickel as flakes, powders, wires, and coated spheres. The shapes available include sheets, strips, washers, tubes, and customized geometries.

The term “EMI gasket” is consistent with the generic industrial definition of a gasket. The electromagnetic fields being shielded impinge on the conductive materials of the enclosure. The incident field induces currents in the enclosure walls. Seams represent discontinuities in shield current paths with resulting voltage differentials across the seams. The purpose of the EMI gasket is to reduce the voltage differential across the seam because the strength of the field emanating from the seam is directly proportional to this voltage.

Depending upon function and application, electronic equipment operates in an extremely wide range of electromagnetic environments (EMEs) in terms of both intensity and frequency. The environments can vary from that of the home to the battlefield. Since there is no “one size/type fits all” gasket, the challenge facing equipment designers is that of choosing the most efficient and cost-effective gasket for their particular application.

An essential parameter in this selection process is the degree to which the gasket prevents electromagnetic energy impinging on one side of the metal joint containing the gasket from coupling through the joint to the other side (i.e., the gasket’s electromagnetic shielding capability). Many factors determine the electromagnetic seal provided by an EMI gasket, including the following:

- a) Gasket material
- b) Gasket construction and geometry
- c) Geometry of the joint
- d) Condition of the contact surfaces
- e) Method of fastening
- f) Closure pressure
- g) Nature of the impinging field

The ideal EMI gasket measurement technique would reveal the full range of effects caused by mounting surface variations, aging, and fasteners and would provide results that indicate the behavior expected from the gasket as installed. Currently, no single measurement technique does this over the frequency range of direct current (dc) to 18 GHz.

1.2 Scope

The scope of this guide is to provide manufacturers of gaskets and designers of electronic systems appropriate methods for the characterization of gaskets. This document will guide the user in the selection of the appropriate test method in order to determine the level of shielding provided in the intended application.

1.3 Purpose

The purpose of this guide is to provide guidance on the strengths and weaknesses of each of the recommended methods, and provide in-depth documentation for each method. Therefore, it identifies limitations and sources of errors of the commonly accepted techniques for measuring gaskets, and provides a basis for comparing the various accepted techniques. It encompasses measurements of the as-installed

behavior of gaskets as well as manufacturing-related quality control measurements. Special attention is also given to test methods for small samples of gaskets (also above 1 GHz), correlation between different methods, and to identify possible measuring methods for near-field characterization of gaskets [as used on printed circuit board (PCB) board applications].

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must 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 referenced, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI/NCSL Z540.1-1994 (Reaff 2002), American National Standard for Calibration—Calibration Laboratories and Measuring and Test Equipment—General Requirements.¹

ANSI/NCSL Z540.2-1997 (Reaff 2007), American National Standard for Expressing Uncertainty—U.S. Guide to the Expression of Uncertainty in Measurement.

ASTM D4935-1989, Standard Test Method for Measuring the Electromagnetic Shielding Effectiveness of Planar Materials.²

Def Stan 59-103 (9 July 1992), EMI/EMP Gasket Components.³

IEEE Std 299™-2006, IEEE Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures.^{4, 5}

MIL-DTL-83528C-2001, General Specification for Gasketing Material, Conductive, Shielding Gasket, Electronic, Elastomer, EMI/RFI.⁶

SAE ARP 1173-1975 (Reaff 2004), Test Procedure to Measure the RF Shielding Characteristics of EMI Gaskets.^{7, 8}

SAE ARP 1705-2006 (Rev. A), Coaxial Test Procedure to Measure the RF Shielding Characteristics of EMI Gasket Materials.

3. Acronyms and abbreviations clause

ARP	Aerospace Recommended Practice
dBμA/m	decibels above a microampere per meter

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² ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (<http://www.astm.org/>).

³ Def Stan 59-103 has been withdrawn; however, copies can be obtained from Ministry of Defense, Directorate of Standardization, Kentigern House, 65 Brown Street, Glasgow G2 8EX, Scotland (<http://www.dstan.mok.uk/>). They are also available in the United States from IHS Inc., 15 Inverness Way East, Englewood, CO 80112, USA, tel. (800) 525-7052 (<http://www.ihs.com/>).

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⁷ SAE ARP 1173-1975 is currently under major revision.

⁸ Aerospace Recommended Practices are available from the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096, USA (<http://www.sae.org/>).

dB μ V/m	decibels above a microvolt per meter
EME	electromagnetic environment
EMI	electromagnetic interference
MSC	mode stirred chamber
PCB	printed circuit board
RoHS	restriction of hazardous substances
SAE	Society of Automotive Engineers
SE	shielding effectiveness
TEM	transverse electromagnetic

4. Factors affecting gasket performance

Figure 1 illustrates a typical application where the EMI gasket is placed underneath the lip of a cover to close the gap between it and the base enclosure. Other similar applications are under connector shells, waveguide flanges, filter cans and meter flanges and in seams. The objective of the gasket is to provide an electrical path across the gap in the shield such that the impedance of the path through the gasket approaches that of a comparable span of the base shield. The impedance of the gasket is a function of its materials and construction, its geometry, and the interface between it and the shield.

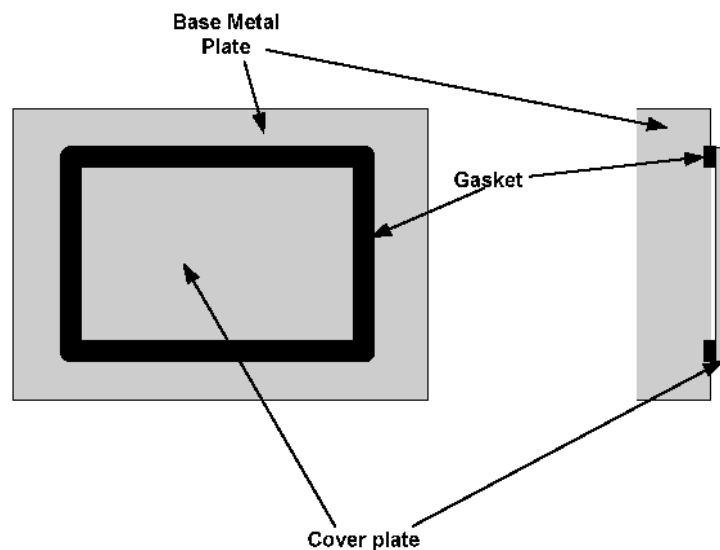


Figure 1—Typical gasket application

All gasket materials have resistive, inductive, and capacitive properties that may exhibit themselves over different portions of the frequency band. The property, which determines the gasket's predominant characteristic, depends on the materials and construction of the gasket as well as the geometry of the joint.

Most gaskets can be considered resistive at low frequencies. Those gaskets constructed of metal filaments (oriented wires or wire meshes) and fingers or spirals typically appear as an inductance in series with a resistance. Gaskets formed from conductively loaded polymers typically appear as a shunt capacitance in parallel with a resistance. These complex impedances determine the effectiveness of the gaskets as frequency increases. Therefore, reliance on volume resistivity data taken at dc or at power frequencies can be very misleading.

All gaskets behave as a complex network of resistors, inductors, and capacitors at frequencies where their physical dimensions become significant fractions of a wavelength or the spacing between constituent

elements approach or exceed resonant dimensions. Further, the gasketed joint is polarized. This polarization is the consequence of the joint being long and narrow and of the gasket conductors being preferentially aligned with a field component of the incident wave.

Furthermore, the cross section of the gasket (circular, rectangular) and the mechanical design of application (flat/flat surfaces, groove structure, compression rate, or closing pressure, etc.) may have a dominant effect on the final behavior of the gasketed joint. Also, special care must be taken for the mating surfaces, concerning possible corrosion over the lifetime and the requirements set by the RoHS restrictions.

The gasketed joint can behave like a section of waveguide filled with conductive materials. When this happens, the gasket and aperture will exhibit complex radiation and transmission properties, and coupling through this aperture is likely to be of greater importance to shielding effectiveness (SE) than the enclosure itself. Where the gasket does not appear homogeneous, it is not safe to assume that the current through the gasket is uniform or that it is determined by the shield. The characteristics of the incident field should also be considered, the radiation characteristics of the total aperture must be recognized, and the propagation of the coupled wave through the “loaded” aperture must be taken into account.

Shield current encounters both the contact impedance between the gasket and the impedance of the gasket itself. On the contact surfaces, there are often films of metal oxides and sulfides, paints, cleaners, dust, dirt, and environmental deposits. Such films will likely be present on gasket surfaces as well.

NOTE—Many surface films or treatments are nonconductive. Depending on the compression-deflection properties of the gasket material, the nature of its conductive elements (e.g., “gritty” particles, oriented wires, knitted wires, etc.), and the closure force applied, certain gaskets will “bite” through such films more effectively than others. This “biting” may or may not be desirable depending on the application environment as it may open a site for corrosion or galvanic action over the life of the equipment. Environmental testing should be considered for every application.

WARNING

Special attention must be given to the requirements as set by the RoHS restrictions.

The path for current from the shield to the gasket will be through the ridges and valleys on the mating surface that result from machining or casting imperfections to the contacted portions of the gasket materials. The contact impedance between the gasket and the parent shield can be a significant factor in the overall behavior of the gasket. This contact impedance will have reactive components in addition to resistance. For example, there is usually some capacitive coupling between the contact surface and the conductors in the gasket.

In addition to the impedance of the gasket and the gasket-to-shield interface, the shield current encounters the resistive and inductive elements of the shield itself, and a portion flows around the gasket via the stray capacitance between the two pieces of parent material. This capacitor is labeled as “shield-to-shield impedance” in Figure 2.

In some cases, the gasket characteristics may be masked by the behavior of the test fixtures, and care must be taken when making the interpretation about the applicability for an actual design, starting from measured data, collected from a measuring setup performing under other electromagnetic conditions.

Thus, the current path through a gasket is a complex network like that illustrated in Figure 2. As complex as this network appears, it is actually somewhat of a simplification. Particularly at very short wavelengths, the gasketed joint will also behave in somewhat the same way as the braid of a coaxial shield, which permits energy to “leak” through. Depending upon the specific configuration of the conducting elements of the gasket, these openings can render the gasket practically transparent at particular frequencies or over certain frequency ranges (see Quine [B28]).

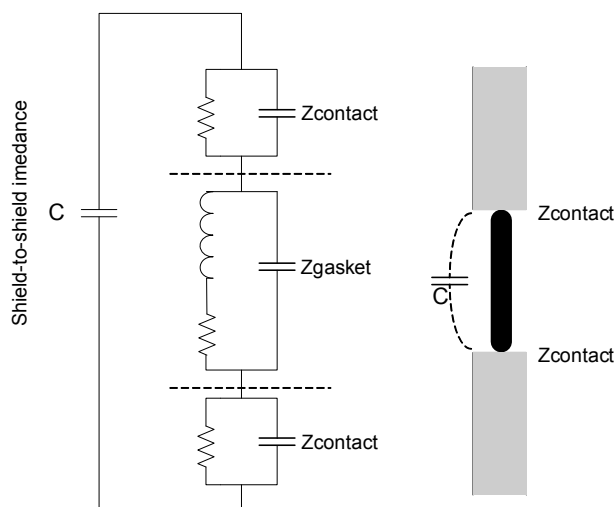


Figure 2—Equivalent circuit of current path through a gasket

Coupling through the gasketed joint will also be influenced by the length of the joint and the number and spacing of fasteners, and the degree to which the gasket material conforms to the joint's gaps and irregularities and maintains electrical continuity between the shield members. As the joint or seam approaches a resonant length, or as the spacing between fasteners approaches resonance, coupling through the aperture can be maximized or minimized according to the impedance match to the incident field.

Minimal power transfer from a source to a load occurs when their impedances are severely mismatched, i.e., high-to-low or low-to-high. Typically, the maximum mismatch is provided by an open or short circuit. Since the goal of a shield is to minimize the power transfer from a radiating source to a susceptible load or to the environment, the shield including any gaskets must present a high degree of mismatch to the impinging wave or to its "load," which is likely to be free space. Both the impedance of the shield-gasket combination and that of the incident field affect this match.

5. Gasket measurement techniques

Standardized measurement techniques consist of the transfer impedance measurement of SAE ARP 1705-2006 (Rev. A) and the aperture transmission implementations of SAE ARP 1173-1975, Def Stan 59-103 (9 July 1992) (obsolete since 1996), and MIL-DTL-83528C-2001.

Other methods are based on alternative ways of acting but are directly related to these standards, such as effective transmission aperture, slot aperture, and the use of (nested) reverberation room techniques (see IEC 61000-4-21:2003 [B14] for the use of reverb chambers).

Even other methods are not related to any standard at all. They are all based on the characterization of shielding materials or small boxes.

In Clause 6, Clause 7, and Clause 8, these methods are discussed in more detail, and references are made to more fundamental papers and documents that may provide an in-depth understanding of the different methods.

Each method possesses particular strengths and offers unique advantages in specific situations.

For example, the technique of SAE ARP 1705-2006 (Rev. A) provides a direct indication of the transfer impedance of the gasket, and consequently the conductivity of the shield-gasket combination.

The aperture transmission measurement technique provides shielding results that are very attractive to equipment and system designers who tend to visualize gasket performance in such terms. However, the field attenuation exhibited by a gasketed seam is strongly dependent upon the nature of the electromagnetic field applied.

The effects of the aperture used for measurements can also overshadow the attenuation provided by the gasket alone. Because of the many factors that can affect measurement results, data taken under different test conditions can be markedly different. Further, test results are hard to relate to the gasket's intrinsic transfer impedance.

The standardized aperture transmission techniques measure the signal coupled through the gasketed aperture at specific antenna orientations and look angles. As previously noted, however, the signal coupled through the gasket is strongly influenced by the measurement antenna locations relative to the aperture and by the surrounding enclosures. To fully characterize the coupling through the gasket, the illuminating antenna should be moved about so as to expose the seam to various incident field conditions. Since each possible antenna pairing involves a measurement of the coupling with and without a gasket present, the effort to perform the evaluation is high.

The effects of enclosure and fixture resonances must be recognized. Fixture resonances currently limit the transfer impedance technique to below about 2000 MHz. The chambers used with the radiated techniques are resonant cavities. Once their longest dimension (typically the distance between diagonally opposite corners) reaches one-half wavelength, resonant modes exist from that frequency upward. Some of these resonances can be very sharp. Consequently, very small changes in antenna position inside the chamber can produce very large changes in the measured signal level. In addition, the size of the aperture influences the attenuation of the field coupled through it. If the aperture is significantly less than one wavelength, the attenuation through it is very high and is inversely proportional to frequency. This attenuation limits the lowest frequencies that can be effectively measured and can restrict the types of gaskets that can be accurately evaluated.

Chamber resonances and aperture dynamic range requirements tend to restrict radiated tests to above about 200 MHz for the size chambers and apertures typically used in the measurement of gaskets. New techniques taking into account these effects by the characterization of the Q -factors of the chambers have been developed by Holloway et al. [B13].

Between about 200 MHz and 2000 MHz, the potential for direct comparison between the standardized techniques exists. However, both below and above these overlap regions, direct comparison is difficult. For example, below the overlap region, the transfer impedance technique provides information on the plane wave and magnetic field behavior of the gasket, whereas the radiated techniques largely provide information on electric and magnetic field behavior. Above the overlap region, the transfer impedance fixture exhibits strong resonances that make comparison of its results with the plane-wave data of the radiated techniques difficult.

6. Standardized gasket measuring techniques

6.1 Transfer impedance—SAE ARP 1705-2006 (Rev. A)

6.1.1 Measuring principle

The gasket illustrated in Figure 3 shows a typical application of a gasket in between two parts of a shielding enclosure. It is important to note that not only the conductive part of the joint will be characterized, but also that the stray capacitances formed by the overlapping parts with lengths L_1 and L_2 may influence the total behavior of the gasketed joint.