SAE ARP-1705 Transfer Impedance and MIL-STD-285 Shielding Tests

The electromagnetic discontinuities at the movable mating surfaces of the shielded enclosure determine the overall shielding effectiveness.

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INTRODUCTION

The most significant single EMC design element for mitigating interference and susceptibility effects is an RF shielded enclosure. The enclosure is used as a barrier to exclude external RF energy and/or to contain RF energy created within the enclosure. The shielded enclosure is designed as a homogeneous container with no electromagnetic discontinuities. This can be achieved only in an all welded enclosure with no penetrations. Unfortunately, an enclosure without penetrations is not practical because most must have external controls, access panels, ventilation openings, viewing apertures, cable entrances and the like. The electromagnetic discontinuities at the movable mating surfaces of the shielded enclosures determine the overall shielding effectiveness and must therefore be minimized. The most common method of minimizing the discontinuities is the use of RF gaskets to electrically interconnect them. At the present time, RF gaskets can only be evaluated by measurement.

ANALYSIS OF SHIELDING EFFECTIVENESS

Shielding effectiveness is extremely difficult to analyze mathematically. The exact solution requires solving Maxwell's field equations for a three-dimensional space surrounding the enclosure. The enclosure represents an abrupt change in the boundary value conditions that interact with and affect the electromagnetic field distribution. Even with finite element analysis (FEA) techniques, exact solutions are available only for simpler geometries and only for homogeneous materials without discontinuities. Several approximation methods are in use to estimate shielding performance. The two described below are the most widely accepted.

TRANSMISSION LINE APPROACH

The transmission line approach was developed by Schelkunoff in the early 1940s and describes the shielding effectiveness in terms of the energy that is simultaneously absorbed within and reflected by the shielding material. This approach is easy to visualize and is frequently used in presentations describing the theory of shielding. Schelkunoff's method is particularly well suited for large homogeneous enclosures without discontinuities where the wavelength is long with respect to the dimensions of the enclosure. The transmission line approach cannot currently be used to analyze RF gasket materials, because it does not account for the size of the enclosure and in

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addition, it does not result in accurate estimates of magnetic or electric field attenuations at low frequencies where dimensions of the enclosure are small with respect to the wavelength. Schelkunoff's approach has been modified by Richard Schulz and the combined Schelkunoff-Schulz analysis method, although much improved, still has problems estimating the magnetic field attenuation. The most accurate analysis approach for the magnetic field shielding was developed by King in 1933 and is based upon Maxwell's equations.

CIRCUIT APPROACH

The circuit approach was developed by Wheeler in the mid-1950s to estimate magnetic field shielding of an enclosure. The technique has been expanded to include magnetic, electric, and plane wave shielding. The circuit approach describes the shielded enclosure as either a short circuited loop antenna for magnetic fields or a fat electric dipole antenna for electric and plane wave fields. Modeling the enclosure as an antenna permits the circuit approach to provide answers that consider the overall size of the enclosure as well as the shielding material characteristics. The method can be used to determine the amount of RF current that can be induced into the skin of the enclosure (as an antenna structure of a given size) and what levels of electromagnetic fields will be developed within the interior of the enclosure by the induced currents. The method would be easier to adapt for the analysis of apertures or discontinuities than the transmission line approach, but it still does not permit accurate estimates of RF gasket material effectiveness.

EFFECTS OF MATERIAL CHARACTERISTICS

Regardless of whether direct measurement or analysis by means of either the transmission line approach or the circuit approach is used to estimate shielding effectiveness, the material that is used for the shielded enclosure will determine the maximum shielding effectiveness. The shielding effectiveness is directly related to the surface transfer impedance (Z_{st}) of the material:

$$\text{Attenuation (dB)} = 20 \log \left(\frac{Ze}{Z_{st}}\right) \quad (1)$$

The surface transfer impedance is the voltage-to-current ratio for the tangential-electric-field developed on the interior of the shield to the driving surface current density on the exterior shield surface created by external RF excitation sources. The surface transfer impedance (Z_{st}) is a complex quantity which combines both the surface resistance (R_s) of the material and its surface inductive reactance (X_{sl}).

For the simple geometry of a spherical enclosure, Rickets[1] shows that for low frequencies or for very thin shield materials where the skin effect is not significant (t << skin depth), the electric field shielding effectiveness (as a ratio) is given as:

$$\frac{E_{\perp}}{E_o} = j\,\frac{3}{2}\,\frac{\omega \varepsilon r}{\sigma t} = j\,\frac{f r 10^{-9}}{2 \sigma t} \quad (2)$$

This equation shows that, at low frequencies, the conductivity (σ) is the most important characteristic of the shield material. However, as the frequency increases, the inductive reactance begins to affect the shielding and the relationship becomes:

$$\delta = \left(\frac{2}{\omega \mu \sigma}\right)^{1/2} \quad (3)$$

$$\frac{E_{\perp}}{E_o} = j\,\frac{f r (2.718)^{(t^2 \pi f \mu \sigma)^{1/2}}\, 10^{-9}}{6 \sigma^{1/2} (2 \pi f \mu)^{-1/2}} \quad (4)$$

where:
ω = $2\pi f$
π = 3.14159
f = frequency
ε = permittivity of free space
r = radius
t = thickness of shield
δ = skin depth
μ = material permeability
j = $\sqrt{-1}$

As this equation shows, the shielding effectiveness at higher frequencies is also a function of the materials permeability, but the conductivity (σ) is still the most important characteristic of the shield material.

The conductivity (σ) and permeability (μ) determine the intrinsic impedance of the shield material:

$$Z_i = j\left(\frac{\omega \mu}{\sigma}\right)^{1/2} \quad (5)$$

The intrinsic impedance and the surface transfer impedance become equal for material thicknesses greater than approximately three (3) skin depths. Thus the measurement of the surface transfer impedance can be used to determine variations in the material characteristics that most directly influence the shielding effectiveness of that material.

MEASUREMENT OF TRANSFER IMPEDANCE

Shielding materials (including RF

gaskets) for cables and for enclosures can be evaluated and classified by measurement of their transfer impedance. The transfer impedance measurement is performed using a coaxial transmission line configuration or fixture (Figures 1a and 1b). Over the test frequency range, RF current is driven through the test sample. The resistive and inductive losses which make up the combination of transfer impedance plus any series contact impedances cause an RF voltage to be developed across the current conduction path. As Ohm's law indicates, the ratio of the measured voltage (V) to the current (I) which created it defines the transfer impedance, i.e.:

$$Z_t = \frac{V}{I} \qquad (6)$$

The Society for Automotive Engineers' Aerospace Recommended Practice, *SAE ARP-1705 Coaxial Test Procedure to Measure the RF Shielding Characteristics of EMI Gasket Materials*, is a transfer impedance test procedure which uses a standardized coaxial fixture. The tests to this procedure are performed as described above (Figures 2a and 2b). Since the test sample conductor path length influences the transfer impedance, the use of the SAE ARP-1705 test method for evaluation of RF gaskets requires the data to be normalized to a standard distance. A length of 1 meter has been chosen as the standard length.

The transfer impedance measurement provides data that is directly related to the characteristics of the shielding materials that directly affect their ability to act as a shield. The transfer impedance data applies only to the test sample, and is isolated from other influences. In addition, the measurement can be performed with easily obtainable test equipment and has excellent repeatability with error values of less than 2 dB. This permits small changes in gasket geometry and in gasket materials to be easily determined.

Unfortunately, the attenuation data based upon transfer impedance is not the same as shielding effectiveness. The attenuation values based solely on the transfer impedance are always lower than radiated shield attenuation data because of the characteristic impedance of the transmission line configuration with respect to the localized ground reference. The typical range of impedances for coaxial cables is 70 to 300 ohms. This equates to a data offset in the range of 36 to 50 dB. Coaxial line impedance (Z_t) to shielding correlation measurements typically use 38 dB as a default value. Although there may be some deviation in the default value, since the gasket test fixture is a coaxial configuration, a 38 dB default value can be applied to the transfer impedance measurement in order to approximate the shielding effectiveness of an enclosure using

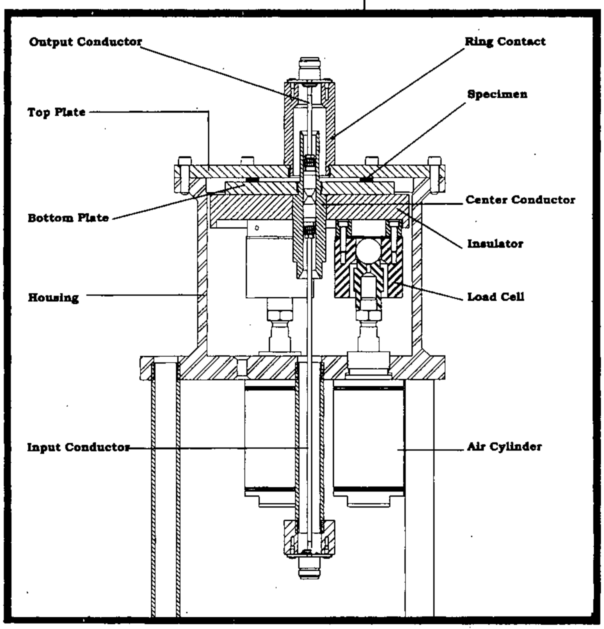

FIGURE 1a. *Schematic of Coaxial Text Fixture for Transfer Impedance Test.*

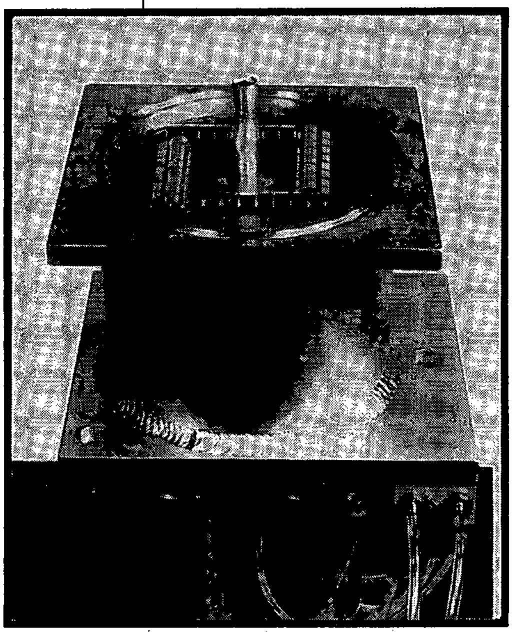

FIGURE 1b. *Interior View of Transfer Impedance Test Fixture Showing Test Fixture in Place.*

the gasket. This 38 dB default value represents the correlation between shielding effectiveness (SE dB) and transfer impedance (Z_t dB), i.e.:

Shielding Effectiveness (SE dB) = Transfer Impedance (Z_t dB) + 38 dB

Since the characteristic impedance of the transmission line is generally not well known, it has been argued that such correlation is not dependable. But by presenting only the transfer impedance data for shielding comparisons, the correlation problem is eliminated and the reported data is very accurate and repeatable. This is not true of the radiated shielding effectiveness measurements performed through an aperture in an enclosure. Radiated measurements are very uncertain and at frequencies that do not correspond to the shielded room resonance can vary as much as 20 dB because of internal room reflections. At room resonance the variation can be as much as 60 dB. Also, at lower frequencies the attenuation of the aperture itself makes the gasket attenuation appear higher.

MEASUREMENT OF SHIELDING EFFECTIVENESS

Since the various mathematical modeling methods are not yet accurate enough to predict the influence of small apertures, cable penetrations, and RF gasket materials, and the transfer impedance test only measures material characteristics, the only way to evaluate the shielding effectiveness of a real enclosure is by direct measurement.

Most of the shielding effectiveness measurement standards use similar approaches. Shielding effectiveness for the various types of fields is measured by first establishing an incident magnetic, electric, or plane wave field strength level without the shield being present, and then recreating the original field strength levels with the shield present.

The ratio of the field with and without the shield present is the measured shielding effectiveness. These shielding effectiveness (SE) levels at each of the measured frequencies, are normally presented in terms of the decibel, which is:

$$SE\ (dB) = 20 \log \left(\frac{F_i}{F_e}\right)$$

where

F_i = Incident field strength (before shielding)

F_e = Exiting field strength (after shielding)

MIL-STD-285, which was released in 1956, is the most well known of the shielding requirements documents. MIL-STD-285 is used to determine if the shielded enclosure is adequate to protect

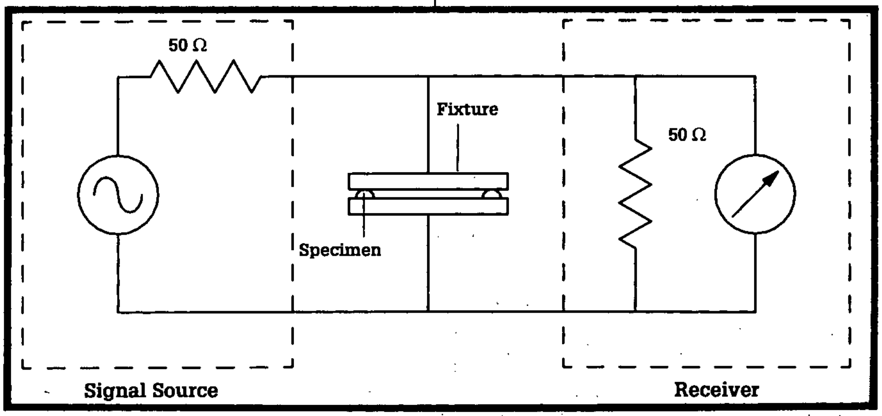

FIGURE 2a. *Schematic of Transfer Impedance Test.*

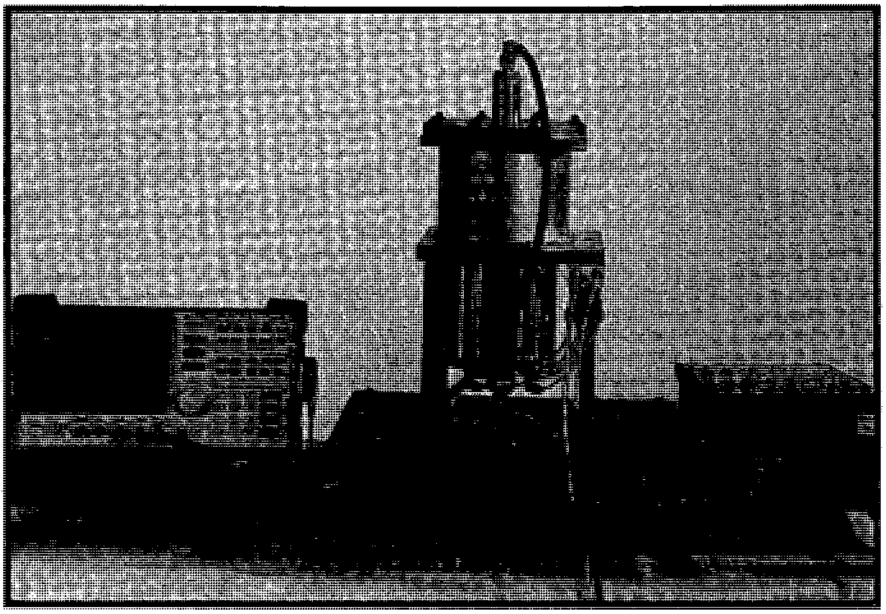

FIGURE 2b. *Transfer Impedance Test Setup.*

the equipment contained within the enclosure from outside RF sources. The MIL-STD-285 measurement procedure requires pairs of either loop, rod, or dipole antennas capable of operating at the test frequencies to be set up outside the enclosure at a separation distance of 2 feet plus the enclosure wall thickness. A high-level signal source is connected to one of the antennas and used to transmit a high-level reference field. This field is measured using a calibrated receiver which is connected to the other antenna. The two antennas are then positioned with the transmit antenna twelve (12) inches from the outside of the enclosure wall and the receive antenna located twelve (12) inches from the inside of the enclosure wall. The high-level reference field is re-established, the enclosure integrity secured, and the attenuated field is then measured. The reduction of the field strength in dB is the attenuation of the enclosure.

No measurements are required by MIL-STD-285 to determine how much attenuation the enclosure provides for RF sources located inside the enclosure. To do so would only require that the positions of the transmit and receive antenna be interchanged. This data would indicate lower shielding effectiveness and could be used as worst case data. This technique is used, however, for TEMPEST evaluations and to measure RF gaskets.

APPLICATION OF SHIELDING MEASUREMENTS TO RF GASKETS

The MIL-STD-285 modification used as an RF gasket evaluation procedure is very clear, and has been in use since the early 1960s. It consists of modifying an electromagnetically tight shielded enclosure by cutting a 24" x 24" square hole in its side about midway between the floor and the ceiling. The hole is then covered by a metal plate that has a shielding effectiveness equal to or greater than the unmodified enclosure. Antennas are placed on either side of the plate-covered hole and a MIL-STD-285 shielding effectiveness test is then performed on the enclosure at the location of the plate (Figure 3). The attenuation is limited by the RF gasket and the measurement thus represents the gasket.

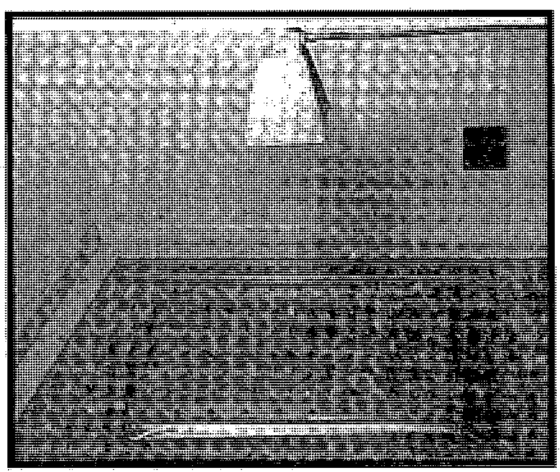

FIGURE 3. MIL-G-83528 Test Setup.

MIL-STD-285 ignores the problems of reflections from the conducting wall surfaces, enclosure resonance, and antenna loading. The minimizing process is time- consuming and not repeatable. In addition, the cover plate acts as a slot antenna which has significant directivity plus the 24" x 24" dimension provides shielding at the lower frequencies. The upper and lower attenuation boundary values are given by the following equation.

Shielding effectiveness:

$$SE\ dB = k \log \frac{\lambda/2}{L}$$

Where:

λ = Wavelength = F/c
F = Frequency
c = Speed of light = 300 for F (MHz) and λ (m)
k = 20 for thin slot
= 40 for a round hole

A 24" x 24" aperture has a diagonal distance of 33.9" which equals 0.85 meters. The frequency (MHz) whose half-wavelength corresponds to 0.85 meters is:

$$\frac{\lambda}{2} = 0.85$$
$$\lambda = 1.7 \text{ m}$$
$$F \text{ (MHz)} = 300/1.7 = 176 \text{ MHz}$$

Thus for frequencies less than or equal to 176 MHz the aperture provides attenuation. For example, at 17.6 MHz the shielding effectiveness equation indicates an aperture attenuation greater than 20 dB but less than 40 dB.

Reflections, resonances, and aperture attenuations are the greatest measurement problems with radiated measurements of shielding effectiveness. These problems introduce errors into the measurements which should be minimized during the measurement procedures but frequently are not. In an attempt to standardize the modified MIL-STD-285 procedure for silver-filled elastomers, a new standard called MIL-G-83528 was created. MIL-G-83528 is a modified MIL-STD-285 procedure which attempts to standardize the aperture dimensions and test setup. Unfortunately, it falls short of being an error-free procedure because it is based on a radiated technique. Radiated measurements are very uncertain and at frequencies that do not correspond to the shielded room resonance, can vary by as much as 20 dB. At resonance the variation can be as much as 60 dB.

SUMMARY

The transfer impedance measurement provides data that is directly related to the characteristics of the shielding materials that determine their ability to act as a shield. In addition, the measurement can be performed with easily obtainable test equipment and has excellent repeatability with error variations of less than 2 dB. This permits small changes in gasket geometry and in materials to be easily determined. Unfortunately, the attenuation data based upon transfer impedance is lower than radiated shield attenuation data by approximately 38 dB. This is because the measurement is influenced by the characteristic impedance of the transmission line fixture with respect to the localized ground reference. Still, SAE ARP-1705 is the most widely accepted RF gasket test method in the United States.

The radiated MIL-STD-285 measurement (in the form of MIL-G-83528) provides data that is evaluated similarly to the way the enclosure would be evaluated. The data that is obtained is the shielding effectiveness of the enclosure with an installed gasket. Unfortunately, the measurement uncertainty is as much as 20 dB to 60 dB because of reflections, resonance, and aperture attenuation. This large error difference makes it impossible to choose between different gasket types based on MIL-STD-285 data, because the variation from one type of gasket to another is often less than the measurement error.

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