ACCURATE SHIELDING EFFECTIVENESS MEASUREMENTS USING A REVERBERATION ROOM.

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ABSTRACT

This paper describes the reverberation room method for shielding effectiveness (SE) measurements. Existing standards for shielded enclosures, cabinets and constructions with gaskets do not give repeatable results.

Two effects can heavily influence SE measurement results:
- Reflections and resonances in a shielded enclosure.
- Ray beams through seams.

Several SE measurement results using the reverberation room method are given. The results appeared to be very repeatable contrarily to the classic shielded enclosure measuring standards.

INTRODUCTION:

SURVEY OF METHODS

METHODS FOR ENCLOSURES.

Several standards for measuring shielding effectiveness (SE) of enclosures are established many years ago. Well-known standards are MIL-STD 285, NSA 63-6, NSA 73-2A and VG 95573, part 15, which describe shielding effectiveness (SE) measurement techniques for shielded enclosures and cabinets [1,2,3,4].

These standards describe SE measurement procedures up to 400 MHz, 10 GHz, 1 GHz and 1 GHz respectively. These measurement methods are time consuming and produce awkward and non-repeatable results in some applications.

DISADVANTAGES.

In the frequency range \( f_0 \) and higher, wherein \( f_0 \) is the lowest resonance frequency, reflections in an enclosure can influence SE measurements in such a manner that these measurement techniques cannot be used.

The lowest resonance frequency \( f_0 \) can be found using:

\[
    f_0 = \frac{150 \cdot 10^6}{l} \quad [\text{Hz}]
\]

Wherein: \( l \) = largest dimension of the enclosure [m].

Large errors due to resonances can be made when SE measurements are carried out at spot frequencies, such as described in MIL-STD 285, instead of sweeping through the whole frequency band. As an example, in Figure 1 the shielding effectiveness of a 19" shielding cabinet is drawn. One curve is as specified by the manufacturer, another curve is as measured at our laboratory. The manufacturer has measured at spot frequencies while our measurements, see Photo 1, are carried out using a frequency sweep. The resonances inside the cabinet are causing large differences between the two methods, which are based both on the VG standard.

Another disadvantage is that for high frequencies (> 500 MHz) the electromagnetic field is directed in a beam, which can be compared with optical rays. Therefore the field which is transmitted through the shielding material is focussed in small rays, see Figure 2. Large measurement errors can result when the points of largest leak (= lowest SE) are not searched for.

The MIL-STD 285 has often been misused by shielded enclosure firms certifying their products. Shielded enclosures are qualified for frequencies up to 40 GHz, while the standard is going up to 400 MHz only. The above mentioned effects, reflections and ray beams, have large influence on the results.
METHODS FOR GASKETS.

Several test methods are available for measuring the transfer impedance, instead of the SE, of materials such as gaskets. Gasket suppliers are applying these methods and are using the results for shielding effectiveness performance figures. These methods are basically different from the above mentioned MIL-STD 285, NSA and VG methods.

A simple approach to shielding theory leads into a separation into 4 methods:

1. The field method: Schelkunoff.
2. The circuit method: Kaden, Stoll [5,6].
3. The relative method: Quine [7].
4. The transmission line method: Jarva, MIL-HDBK 419 [8,9,10].

The MIL/NSA/VG method are based on the transmission line approximations (4), see Figure 3 (MIL-HDBK-419, Jarva), while the circuit or transfer impedance methods (2) are based on the continuity in conductivity between materials, see Figure 4.

Although gasket manufacturers suggest, a direct comparison between the SE- and the transferimpedencefigure cannot be made!

METHODS FOR NEW (EXOTIC) MATERIALS.

In recent years several new shielding materials are developed. Examples of these new materials are plastic housing, treated with silver or nickel paint, carbon fibers etcetera.

New test methods are developed to certify these materials. Examples are the ASTM-D 4935, ASTM-ES7, TEM-t, Double-TEM etcetera. All of these test methods have advantages and disadvantages. The common disadvantage of these methods is that only one specific material can be tested, but not a complete construction.

For example, we name the application of carbon fibers. Carbon fiber has a reasonable SE figure, but because carbon is very noble and most metals (aluminum, iron, copper) are not, corrosion problems will arise in practical applications. Therefore specific precautions, i.e. a specific construction, to prevent corrosion must be taken care of, which can have a large influence on the SE performance. Such a construction must be measured to obtain the SE figure for that carbon fiber construction together with the constructive measures to prevent corrosion.
OBJECTIVE

When measuring the SE of porous materials, such as wire mesh screen enclosures, shielded windows and thin coatings on plastic housing, the MIL-STD 285 test setup and using a frequency sweep, instead of spotfrequencies, gives repeatable results.

When measuring massive, solid constructions wherein gaskets are applied, the MIL-STD 285 (and NSA and VG) method cannot be used because of resonances and ray beams! Therefore we must use another method to qualify constructions with specific gaskets.

In 1984 a research project by our company was started to qualify several different gaskets, such as finger strips, knitted wire mesh and conductive polymers, for above-deck navy products. The materials were evaluated with respect to their SE performance between 1 MHz and 10 GHz, but also with respect to their environmental performance such as shock, vibration, humidity, temperature, corrosion etcetera.

At first instance, the MIL-STD 285 method was used. Plastic constructions with thin conductive coatings, such as silver paint, nickel paint, and carbon fibers resulted in satisfactory SE measurement figures, see Figure 5 and 6. However, when measuring gaskets mounted between solid aluminium constructions, see Figure 7, then the measurement results were not repeatable. The SE was very sensitive to:

* the frequency (the resonance problem) and to
* the placement of the antennas (the optical ray problem).

A very repeatable method for an objective comparison between the several types of gasket was needed.

As mentioned in the preceding paragraph, a comparison between the transferimpedance-methods, used by gasket suppliers, and SE figures of a complete construction with the gasket in its application cannot be made. Therefore, other methods are searched for.

In MIL-STD 1344 and MIL-STD 1377 reverberation room methods for measuring the shielding effectiveness of cabinets, gaskets, connectors and cables are described [11,12].

This reverberation room method appeared to be very suitable for qualifying gaskets. The method is used with success for several years by our laboratory for SE measurements of special constructions but also for cabinets.

REVERBERATION ROOM THEORY

Several articles about reverberation rooms are written. In this paragraph we will present only the basics needed for a proper application of the reverberation room technique.

The idea of stirring transverse electromagnetic (TEM) modes in a shielded enclosure with dimensions which are large with respect to the wavelength, and to use this method for EMI measurements, was proposed for the first time in 1968 [13].

The purpose of the reverberation room is to obtain a field which is constant on average, which has many polarisation directions, and which is statistically uniform. This can be achieved by means of two reverberation methods: the mode-tuned and the mode-stirred techniques. Mode-tuning means that at one frequency a mode tuner is turned to that position which results in the maximal fieldstrength. Mode-stirring means that the maximal level in the room is measured while a mode stirrer is turned around. The mode-stirred technique is easier to apply for SE measurements than the mode-tuned technique.

For SE measurements we are only interested in the difference in power density levels in the reverberation room and outside the room. The absolute power density level is of no interest. It is however necessary that the test set up is constant.
The main advantage of the reverberation room method is that the test results are extremely reproducible.

At first instance, a disadvantage of the reverberation room method seems to be the unknown field impedance, which can vary extremely, and so the type of the electromagnetic field: electric, magnetic or electromagnetic.

A definition of electric field shielding effectiveness is:

$$SE_E = \frac{|E_{in}|}{|E_{out}|} [dB]$$  \hspace{1cm} (2)

Wherein: $E_{in}$ = transmitted electric field strength, in dB above some reference (for example, 1 µV/m),

$E_{out}$ = received electric field strength, in dB (same reference).

And for magnetic field shielding effectiveness:

$$SE_H = \frac{|H_{in}|}{|H_{out}|} [dB]$$  \hspace{1cm} (3)

Wherein: $H_{in}$ = transmitted magnetic field strength, in dB above some reference (for example, 1 pT/m),

$H_{out}$ = received magnetic field strength, in dB (same reference).

Using a reverberation room, the definition of shielding effectiveness is:

$$SE_{rd} = \frac{|Pd_{in}|}{|Pd_{out}|} [dB]$$  \hspace{1cm} (4)

Wherein: $Pd_{in}$ = power density inside the reverberation room, in dB above some reference (for example, 1 mW/m$^2$),

$Pd_{out}$ = power density outside the reverberation room, in dB (same reference).

One assumes that, for example, measuring with an electric antenna results in the electric field shielding effectiveness, and measuring in the frequency range wherein an electromagnetic field exists (a plane wave), results in the plane wave shielding effectiveness. This is however impossible, because a shield distorts an electromagnetic field in such a manner that the resulting field in the neighbourhood of the shield is a near-field, and not an electromagnetic (plane wave) field.

As a conclusion, the SE performance of a shielding construction is not the SE for an electric, magnetic or electromagnetic field, but the SE performance of that construction using that specific test method!

The frequency range of a reverberation room is determined by its dimensions. The high frequency limit is the frequency at which the shielded enclosure starts to leak so that the quality factor $Q$ of the room is too low for accurate measurements. The quality factor is defined as $[14,15,16]$:

$$Q' = \frac{3V}{\mu_r S \delta_s} \frac{1}{\lambda^3} \frac{1}{P_r (1 + \frac{1}{P_i} + \frac{1}{P_r})}$$  \hspace{1cm} (5)

Wherein:

$Q'$ = empirically determined quality factor,

$V$ = volume reverberation room in [m$^3$],

$\mu_r$ = relative permeability of the metal of the room,

$S$ = total surface area of the walls in [m$^2$],

$\delta_s$ = skin depth of metal in [m],

$\lambda$ = wavelength of signal in [m],

$a, b, c$ = lengths of the edges of the room in [m],

$P_i$ = power from amplifier to antenna in [W],

$P_r$ = power reflected by antenna to amplifier in [W].

The low frequency limit is the frequency at which at least 20 higher-order TEM modes exist. However, because the reflections in the room disturb measurements according MIL-STD, this method cannot be used for frequencies higher than the lowest resonance frequency (Formula 1). The mode stirrer 'stirs' the resonances, and therefore, a reverberation room used for SE measurements can be used already when three resonance modes, empirically obtained, are present.

The enclosure used for the experiments is 3.42 x 2.85 x 2.22 m, so it can be used as reverberation room for frequencies 80 MHz (3 modes).

**TESTPROCEDURE SE MEASUREMENTS**

In the reverberation room a constant power, generated by a sweep generator and amplifier and transmitted by an antenna, is fed into the room, see Figure 8. Via directional couplers between the amplifier and the antenna the transmitted and reflected power is measured, see Figure 9. When the reflected power is more than half of the transmitted power, which is the case when the quality factor $Q$ is very high, then the measurement results are less accurate.

A small antenna connected to a spectrum analyser, set in "max. hold" mode, is used as receiver. During several minutes a one-octave spectrum is measured. The setup could be made simpler by using a tracking generator.

For the determination of the SE of a construction three different measurements must be performed:

A. Reference level measurement.

B. Dynamic range measurement.

C. Shielding measurement.
A reference measurement is carried out by measuring the power density in the reverberation room while any known leak, for instance the hole for the test object, is closed to ensure a high Q factor.

**DYNAMIC RANGE MEASUREMENT.**

The hole for the device under test (DUT) is closed with an 'ideal' construction. Any leaks, such as cables, connectors and seams will be treated. The reverberation room is searched for any leaks at the outside, for instance nearby the door or the 'ideal plate'. The maximal level (B) shall be noted.

The dynamic range of the test setup is the difference between this level (B) and the reference level obtained via the above mentioned procedure (A).

**SHIELDING MEASUREMENT.**

Subsequently the DUT is mounted in the hole. The points of maximum leakage are located by the receiving antenna and the power density level (C) is measured. It must be at least 20 dB lower than the reference level (A) otherwise the Q in the reverberation room is too low. Furthermore, the level must be more than the dynamic range level (B) otherwise measurement errors are influencing the results.

The SE is the difference between this level (C) and the reference level (A).

Of course it would be better to use also a reverberation room at the receiving side, as described in MIL-STD 1344. This will result in a very long measuring time because two mode stirrers must turn and both must give a maximum at the same time. In practice it appeared that the method with one reverberation room was appropriate for reproducible and accurate SE measurements.

**MEASUREMENT RESULTS**

In Figure 10 the power density inside the reverberation room is given when the mode stirrer inside the room was not turning. The resonances, which are not constant at the same frequency because the resonance frequencies are dependant of the present devices in the room, are obvious! In Figure 11 the stirrer is rotating around its axis. The amplitude level is very constant and the resonances are not determined by the filling and the placement of the antennas anymore.

In Figure 12 some measurement results are given. An interesting result of the measurements was that the shielding effectiveness for high frequencies (>150 MHz) could only be improved using monel as a gasket. The SE performance of conducting rubber was equal to or even worse than using no gasket at all. The dimensions of the crevice determined the performance like it was a large capacitor, see Figure 12. The explanation for this effect can also be a wavelength attenuation such as in optics.

The systematic failures of the reverberation method are within 10 dB, while they are 30 dB for the MIL-STD 285 method.
**CONCLUSIONS**

The results shown in this paper lead to the following conclusions:

- Classic shielding effectiveness measurement techniques cannot be used for testing of massive constructions with gaskets.
- The reverberation room measurement method yields repeatable and accurate SE measurement results.
- With this SE method it became clear that polymers filled with conductive material, such as silver particles, are resulting in a SE figure which is lower than when two constructive parts are mounted directly at each other. This effect can be explained by the capacitor effect of the overlap between the plates. Therefore the small crevice does not function as a small slotted waveguide, which is commonly assumed.
- No extra shielding aids for frequencies above 1 GHz are needed for medium shielding if flat constructions are available. For high SE extra shielding aids will be needed. Then monel-type gaskets are advised.

**REFERENCES**


