Shielding Effectiveness Measurements using a Reverberation Chamber

Frank B.J. Leferink
Thales Netherlands
Hengelo, The Netherlands
frank.leferink@nl.thalesgroup.com

Hans Bergsma
Thales Netherlands
Hengelo, The Netherlands
hans.bergsma@nl.thalesgroup.com

Wim C. van Etten
University of Twente
Enschede, The Netherlands
w.c.vanetten@el.utwente.nl

Abstract
Shielding effectiveness measurements have been performed using a reverberation chamber. The reverberation chamber methodology as well as the measurement setup is described and some results are given. Samples include glass reinforced plastic panels, aluminum panels with many holes, wire mesh, among others. The reverberation chamber setup gives very repeatable measurement results.

Keywords
Shielding Effectiveness, Reverberation Chamber

INTRODUCTION
Shielding effectiveness (SE) measurement methods have been in use over decades. [1][2][3][4][5][6][7][8][9] Every method has its disadvantages. As an example, the conventional MIL-STD 285 [1] test setup used for measuring SE of gaskets is drawn in Figure 1. At high frequencies, where the dimensions of the test setup are larger than the wavelength of the test signal, beams are formed. The position of the beams dependant of pressure and size of the gaskets, and the received power is dependant of frequency and position of the antenna. These effects affect the measurement results and repeatability is drastically reduced. These disadvantages can be overcome when using a reverberation chamber.

Reverberation chambers have been used for decades. The basic objective was the creation of high field strength [10][11]. But already in 1971 [12] the reverberation chamber was used for measuring shielding effectiveness, in this case a missile.

The objective of the reverberation chamber is to obtain a field which is constant on average, which has many polarisation directions, and which is statistically uniform [10][11][13]. This can be achieved by means of either the mode-tuned or the mode-stirred technique, or by varying the boundary conditions of the whole chamber. The mode stirring technique has been used in this work. Mode stirring means that the maximum electromagnetic field level in the chamber is measured while a mode stirrer is moving [14]. The received power in a rectangular chamber without a (rotating) mode stirrer is shown in Figure 2. If the stirrer rotates, the received power is as shown in Figure 3. Although this is a frequency dependant pattern, one can reason that a similar pattern can be observed when the leakage lobes of a gasket are measured as function of the radial position at a fixed frequency.

![Figure 2: Power density inside reverberation chamber when the mode stirrer does not rotate](image2)

![Figure 3: Power density inside reverberation chamber when the mode stirrer rotates](image3)

In [15][16][17] a reverberation chamber test procedure has been given using a nested chamber, as shown in Figure 4. This method needs a much higher frequency for proper operation due to the limited size of the test fixture, compared to the method as described in this paper.

![Figure 4: Nested Chamber method as described in [15](details of the text can be found in [15])](image4)

The procedure we applied is described, and some test results are presented.
SETUP
The test setup described in [20] used is shown in Figure 5. The transmit chamber (right) is the reverberation chamber. In many cases, the field in the receive chamber (left) does not have to be made reverberant, and then a stirrer is not used. The receive antenna is always positioned such that the highest level is measured.

For SE measurements we are only interested in the difference in power density levels in the receive chamber without and with a panel mounted, although one could argue on this, stating that the hole is a part of the shielding (at low frequencies).

The useable frequency range of the test setup is very wide; At frequencies where the reverberation chamber is small with respect to the wavelength of the test signal, the chambers are just shielded chambers. When the chamber size is in the order of a wavelength and the test signal resonates, the results are less repeatable. At even higher frequencies, the reverberation chamber becomes effective because sufficient modes are available so then an uniform field is obtained via the rotating stirrer. 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, although not a very high Q is needed for accurate measurement results. The enclosure used for the experiments is 3.42 x 2.85 x 2.22 m and can be used as reverberation chamber for frequencies above approximately 80 MHz (3 modes).

PROCEDURE
A fixed power level, generated by a tracking generator and amplifier and transmitted by an antenna, is fed into the reverberation chamber. The transmitted and reflected power is measured via directional couplers as shown in Figure 5. If 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 is connected to a measuring receiver linked to the tracking generator. The measuring time is longer than the time needed for 360° rotation of the stirrer, so that the maximum amplitude is measured.

A reference measurement is carried out by measuring the power density $P_{dr}$ in the reverberation chamber with the Device Under Test (DUT) in place. The transmitted level $P_{dl}$ is measured in the receive side. The points of maximum leakage are searched for by the receiving antenna.

To determine the SE of a material or construction a correction is needed for the shielding effectiveness of the hole in the wall itself [22]. Therefore the power density in the reverberation chamber and at the receive side are measured when the hole is open. The difference between these levels is the $SE_h$ of the hole in the wall.

TEST SAMPLES
The test setup has been used to measure the shielding effectiveness of many samples, including

- Composite panels (Glass Reinforced Plastics, GRP) with woven metallic textile
- Composite panels with carbon fibers
- Composite panels with metal paint
- Composite panels with thin metallic fibers
- Honeycomb panels
- Joined panels
- Various wire mesh
- Panels with multiple holes, and
- Aluminum panels with various gaskets

In order to fix the DUT in a repeatable manner, an aluminium pressure ring is applied. The screws are fixed with a torque wrench adjusted to torque 4.

The shielding effectiveness of several GRP panels are given in Figure 6. The repeatability was tested by measuring, removing and again measuring a similar panel several times. The result of such a repeatability test is shown in Figure 7. For comparison, the difference in measurement results obtained using the conventional MIL-STD 285/IEEE299 method could be up to 40 dB in some cases.
The GRP panels have been deliberately damaged and repaired. The impact on shielding effectiveness has been shown in Figure 8. The subscript \(d\) denotes damaged, while the subscript \(r\) denotes repaired.

Repairing a GRP panel was effective for high frequencies, while at low frequencies the SE was reduced after repair. The reason for this was that it was difficult to make electrical contact with the metallic layers in or on the GRP. This reduced the SE at lower frequencies. One would argue that without electrical contact, the seams would be dominant at high frequencies. However, at high frequencies the capacitive effect between the layers dominate.

The shielding effectiveness of one hole is well known: it is open (0 dB) if a half-wavelength equals the largest dimension of the hole. If multiple holes are applied, then several models give different answers, ranging from \(0\log N\) to \(20\log N\) with \(N\) being the number of holes. To investigate the effect, a panel has been used with an increasing number of holes of 15 mm diameter, separated by 35 mm, in a aluminum panel of 2 mm thickness.
The repeatability is at low frequencies, i.e. less than 5 GHz excellent. For higher frequencies the repeatability is still good, and excellent compared to conventional test techniques like MIL-STD 285.

Several wire meshes have been measured. As an example, the SE of some retail wire meshes (‘chicken wire’) woven wire mesh and a mesh used in radar antenna reflectors has been shown in Figure 12. The raw data and a 10 point moving average trend line is shown. The wide frequency range of the test setup and the SE variation are clearly visible; At low frequencies, the SE gives a flat curve. In the mid frequencies, where the chamber size is equal to a wavelength, resonances occur. At high frequencies, the reverberation effect smooths out the resonances.

The objective of the mesh material is to show mechanical design engineers that even chicken mesh is capable to shield electromagnetic fields.

![Figure 12: SE of various wire mesh](image)

**Conclusion**

Shielding effectiveness testing at high frequencies, i.e. wavelength smaller than enclosure size, using conventional test techniques gives large variations in results. Reverberation chambers are much more suitable. The shielding effectiveness measuring method using the reverberation chamber has been described and some results are shown. The measurement results obtained are very repeatable and not dependant of size and quality of chambers. Some interesting conclusions can be drawn. For instance, the leakage of holes in a panel appeared to be either a function of $10 \log N$ and $20 \log N$, $N$ being the number of holes, depending of the size of the holes with respect to the wavelength.

More measurement data on gaskets, honeycomb ventilation panels and labyrinths will be published in the near future.

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