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Recommendations for shielded enclosures

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National foreword

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Recommendations for shielded enclosures

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Foreword

This Technical Report was prepared by the Technical Committee CENELEC TC 210, Electromagnetic compatibility (EMC).

The text of the draft was submitted to vote in accordance with the Internal Regulations, Part 2, Subclause 11.4.3.2 (simple majority) and was approved by CENELEC as CLC/TR 50484 on 2009-03-20.

This document supersedes R210-005:1999.

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1 Scope

This Technical Report applies to shielded enclosures used for EMC testing which are to be validated according to the EN 50147 series of standards and the corresponding international standards. The object of this report is to give guidance to the selection of the shielding materials and components. The frequency range for this document is 10 kHz to 40 GHz.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 50147-1:1996, *Anechoic chambers – Part 1: Shield attenuation measurement*

EN 50147-2, *Anechoic chambers – Part 2: Alternative test site suitability with respect to site attenuation*

EN 55011, *Industrial, scientific and medical (ISM) radio-frequency equipment – Electromagnetic disturbance characteristics – Limits and methods of measurement* (CISPR 11, mod.)

EN 55022, *Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement* (CISPR 22, mod.)

IEC 60050(161), *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

3 Definitions

Void.

4 General

Depending on the particular circumstances, it may be necessary to shield a room from the electromagnetic environment. Conversely it may be necessary to protect the environment from electromagnetic energy generated within the room. Figure 1 illustrates this.

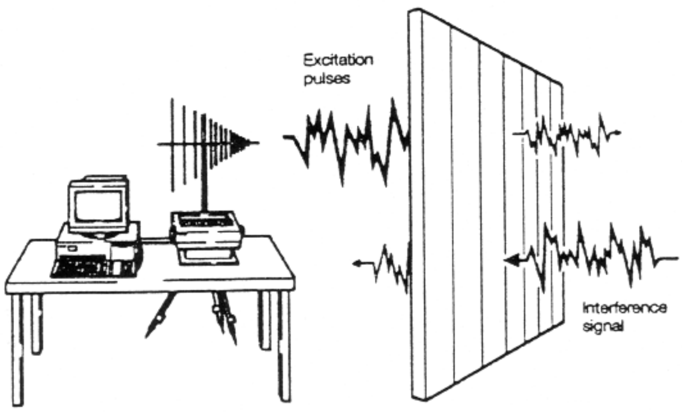


Figure 1 – Illustrated set-up for shielding

5 Shielding

The shielding effectiveness (SE) of a shielded enclosure can be measured, e.g. as described in EN 50147-1, or calculated, e.g. as in 5.1. In general, the SE of a shielded enclosure can only be calculated for simple cases. To do this a number of assumptions are made. The most important of these assumptions is that the envelope formed by the enclosure is homogeneous and consists of material whose properties such as thickness (t), conductivity (σ) and permeability (μ) are well defined. Another assumption is that the shielded enclosure has a simple geometric structure. Normally, steel, copper or aluminium sheets are used to meet the SE requirements.

The SE not only depends on the shield material parameters but also on the wave impedance of the field to be shielded. Consequently, the SE depends on the distance (r) between source and shield, relative to the wavelength λ_0 of the field, normally expressed in the quantity $\beta r = 2\pi r/\lambda_0 = 2\pi f r/c_0$, where f is the frequency and $c_0 = 3 \cdot 10^8\ m/s$ the propagation velocity of the field. Then, three regions are distinguished:

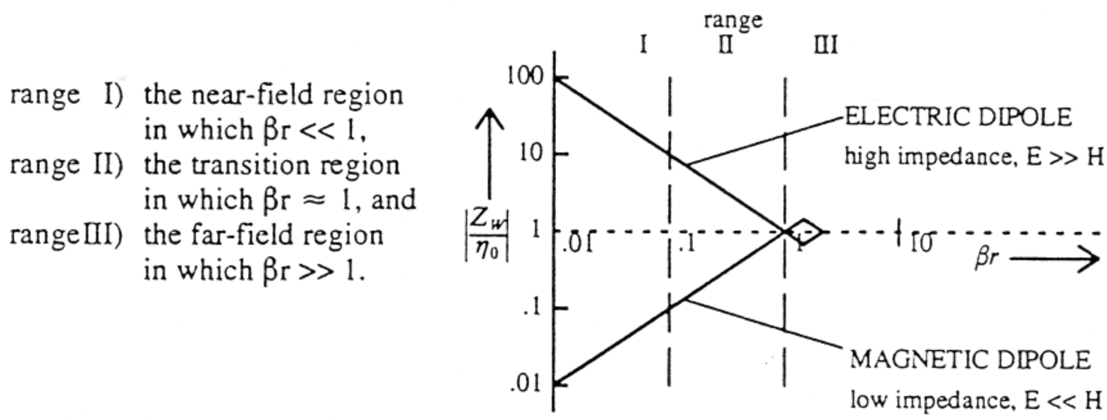


Figure 2 – Wave impedance versus distance of the field source

In the far-field (plane wave, free space) the wave impedance is a constant η_0 = 377 Ω. In the near-field, the wave impedance depends on βr and, consequently, on the type of source. The two most important types of source are:

1) the magnetic dipole having a wave impedance $Z_{wH} \ll \eta_0$, and therefore normally called a 'low-impedance source'. In the near-field Z_{wH} is proportional to βr;

2) the electric dipole having a wave impedance $Z_{wE} \ll \eta_0$, and therefore normally called a 'high-impedance source'. In the near-field Z_{wE} is in inversely proportional to βr.

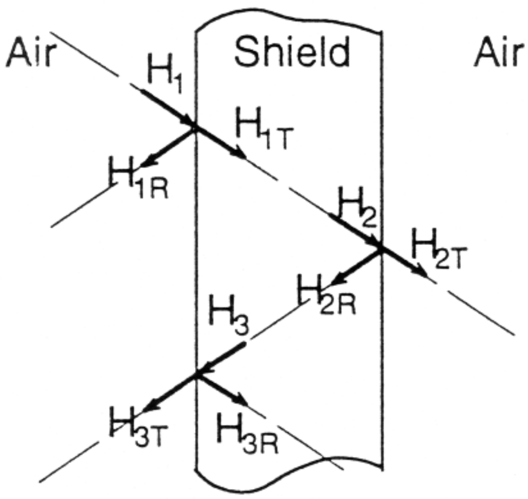
In the near-field region (normally the lower frequency range, say up to 10 MHz) the minimum SE of an enclosure is determined by the SE for the magnetic field component of a low-impedance source. A high SE value is then achieved by using a shield of an adequate thickness with a high value of the relative permeability.

In the higher frequency range (normally f larger than 10 MHz) and in the case that $\beta r \gg$ l a shield with a good conductivity is important. In this range constructional details of the enclosure, such as joints/seems, doors, inserts and resonance effects will limit the final SE of the enclosure, in particular when the largest dimensions of slits and openings in the enclosure are smaller than λ_0. The cable feed-throughs are another source of limitation of the SE.

5.1 Shielding attenuation

In many SE calculations, SE is considered to be equal to the attenuation S of the amplitude of the electric or magnetic component of the EM field as caused by an infinitely large planar shield. In general, this is not correct. For example, in S calculations resonance effects in the field distribution inside a shielded enclosure which will affect the SE are not taken into account. However, S calculations allow a good estimate of SE when considering shielded enclosure requirements. In these calculations the direction of propagation of the EM wave to be shielded is generally taken perpendicular to the shield.

The major basic theories and concepts of shielding were established by Schelkunoff [1] and Kaden [2]. More condensed and detailed practical information can be found in EMC textbooks [3].



The incoming field wave is represented by H_1.

Figure 3 – Schematic diagram of the partial reflections (subscript R) and transmissions (subscript T) at the two surfaces of a shield

According to the Schelkunoff theory, the total attenuation S_T provided by a shield results from three mechanisms, their relation being given by (see Figure 3):

$$S_T = S_A \cdot S_R \cdot S_{MR} = \frac{H_{IT}}{H_2} \cdot \left(\frac{H_1}{H_{IT}} \cdot \frac{H_2}{H_{2T}} \right) \cdot \left(\frac{H_{2R}}{H_3} \cdot \frac{H_3}{H_{3R}} \cdot \dots \right) \tag{1}$$

where

H represents the amplitude of the field component to be shielded.

When expressed in dB

$$S_\tau = S_A + S_R + S_{MR} \quad \text{(dB)} \tag{2}$$

These terms are elucidated in 5.1.1 to 5.1.3, and numerical examples are given in 5.1.4.

5.1.1 The absorption loss term $S_A = H_{1T} / H_2$ i.e. the contribution to S_R as a result of the energy absorption when the field passes once through the shield. S_A can be calculated from

$$S_A = e^{t/\delta} \quad (3)$$

where

δ is the skin depth of the shielding material, given by

$$\delta = \sqrt{\frac{2}{\omega\sigma\mu}} \quad (4)$$

and

$$\omega = 2\pi f .$$

NOTE 1 The conductivity can be written as $\sigma = \sigma_r \cdot \sigma \cdot c_u$, where $\sigma_{cu} = 5{,}8 \cdot 10^7$ S/m is the conductivity of copper and σ_r the conductivity of the shield material relative to copper. Similarly, μ can be written as $\mu = \mu_r \mu_o$, where $\mu_0 = 4\pi \cdot 10^{-7}$ S/m and μ_r the relative permittivity of the shield. Expressing the frequency in MHz, δ can be written as

$$\delta = \frac{66}{\sqrt{f(MHz)\sigma_r \mu_r}} \quad (\mu\text{m}) \quad (5)$$

NOTE 2 S_A does not depend on the distance between source and shield, it only depends on the shield material parameters t, υ, μ and the frequency f. From Equation (3) it follows that $S_A \approx 8 \cdot t/\delta$ (dB).

5.1.2 The reflection loss term $S_R = (H_1 / H_{1T})(H_2 / H_{2T})$, i.e. the contributions to S_T as a result of the reflection of the field when entering and leaving the shield. This contribution is proportional to the wave impedance of the field and, hence, in the near field S_R depends on the type of source via the factor βr as indicated in Clause 5.

a) Near field $(\beta r << I)$:

In the case of an electric dipole source, S_R can be estimated from

$$S_R = S_{RE} = \frac{\sigma\delta}{4\sqrt{2}} \cdot \frac{\eta_o}{\beta r} \quad (6)$$

Note that $S_{RE} \rightarrow \infty$ when $\beta r \rightarrow 0$, i.e. when $f \rightarrow 0$ and/or $r \rightarrow 0$.

In the case of a magnetic dipole source, S_R can be estimated from

$$S_R = S_{RH} = \frac{\sigma\delta}{4\sqrt{2}} \eta_0 \beta r \quad \text{(see the Note to } S_{MR}\text{)} \quad (7)$$

Note that $S_{RH} \rightarrow 0$ when $\beta r \rightarrow 0$, i.e. when $f \rightarrow 0$ and/or $r \rightarrow 0$.

b) Far field $(\beta r >> I)$:

In the far-field the wave impedance is a constant independent of the type of source, and S_R can be estimated from

$$S_R = \frac{\sigma\delta}{4\sqrt{2}}\eta_0 \qquad (8)$$

5.1.3 The multiple reflection factor $S_{MR} = \{(H_{2R}/H_3)(H_3/H_{3R})...\}$ i.e. the reduction factor of the reflection loss S_R $(or\ S_{RE}\ or\ S_{RH})$ due to multiple reflections of the waves inside the shield. This term is only of importance when S_A is small. S_{MR} can be estimated from

$$S_{MR} = 1 - e^{-2t/\delta} \qquad (9)$$

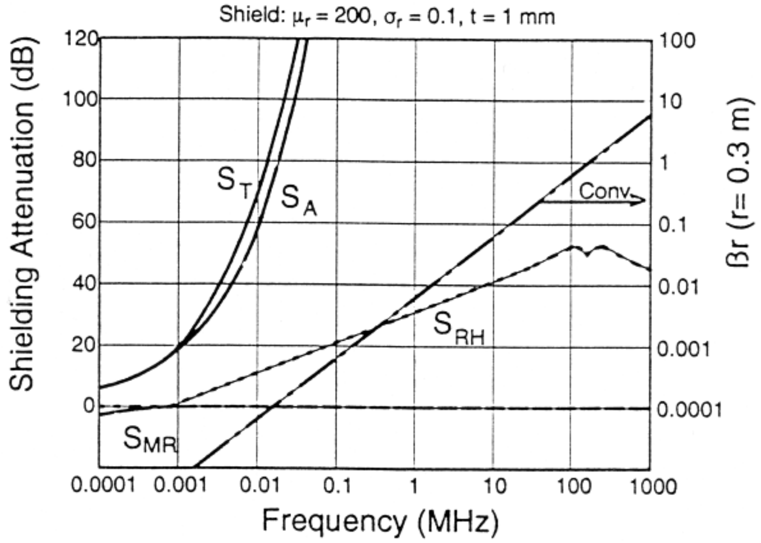
NOTE 3 The product of the reflection loss term and the multiple reflection factor reducing the effective reflection loss is always ≥ 1. This consideration is of importance in the case Equation (6) applies. Therefore, in the aforementioned estimates the following additional condition shall be used:

$$IF\ S_{RM}S_{MR} < 1 \quad \text{then} \quad S_{RM}S_{MR} = 1 \qquad (10)$$

In logarithmic units this means that $(S_{RH} + S_{MR})$ is always positive, with a minimum value of 0 dB, see Figure 4.

5.1.4 Numerical examples: Figure 4 presents an example of results of $S(f)$ assuming t = 1 mm, r = 0,3 m (a relatively short distance to the wall of the shielded enclosure), σ_r = 0,1 (e.g. that of iron) and μ_r = 200 (e.g. the minimum μ_r for cold rolled steel) and a magnetic dipole as the source of the field.

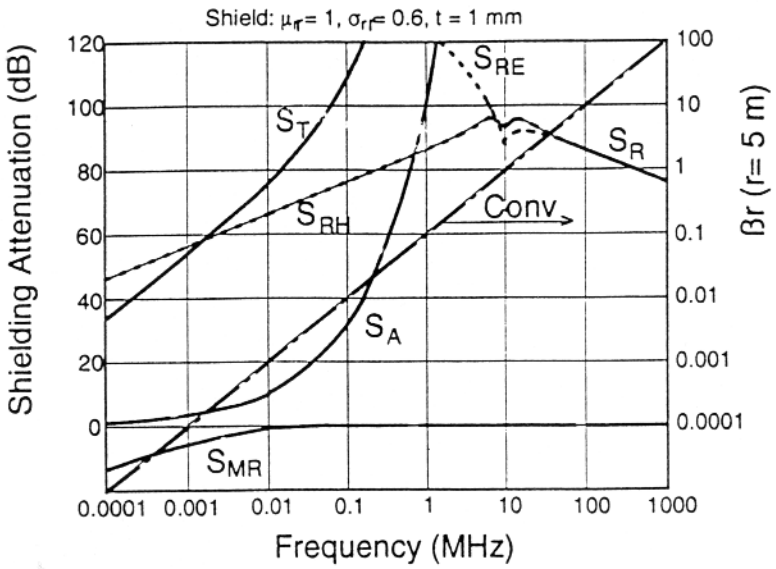
From this figure it can be concluded that due to the low value of r (= 0,3 m), S_{RH} hardly contributes to S_T at frequencies f < 0,01 MHz. At low frequency S_T largely depends on S_A which has a relatively high value as a result of taking shield material with $\mu_\tau >> 1$. At frequencies f > 1 MHz S_T > 150 dB, being completely determined by S_A, which in praxis means that at those frequencies the SE is determined by imperfections of the enclosure, see 5.3.1. The values of S_T in Figure 4 just comply with curve 2, the standard performance curve in Figure 8 in 5.4.



The curve labelled ‘conv’ allows conversion of a frequency value into a βr value, taking r = 0,3 m.

Figure 4 – S results calculated for a low-impedance magnetic field source

Assuming a much large value of r, say r = 5 m, βr = 1 at f = 10 MHz. An example of results of $S(f)$, assuming additionally that t = 1 mm, σ_r = 0,6 (e.g. aluminium), and μ_r = 1, is given in Figure 5.



S_{RE} (high impedance electric field source) is also indicated.

In the far field $S_{RH} = S_{RE} = S_R$.

The curve “Conv” assumes r = 5,0 m.

Figure 5 – Calculated S results for a low-impedance magnetic field source

In this example S_{RH} clearly contributes to S_T. The curve S_T complies with Curve 1, the high performance curve, in 5.4, Figure 8. This example illustrates a consideration often met in SE discussions, in which three frequency ranges are considered, see Table 1 containing a summary of various SE *aspects.*

Table 1 – Summary SE aspects

	Frequency range I *f < 10 MHz*	***Frequency range II*** *10 MHz < f < 100 MHz*	***Frequency range III*** *f > 100 MHz*
λ_0	*> 30 m*	*30 m – 3 m*	*< 3 m*
βr *if r ≈ 5 m*	*≪ 1 near-field region*	*≈ 1 transition region*	*≫ 1 far-field region (plane wave)*
S_A	at / δ	at / δ	at / δ
S_R	$a\sigma\delta\beta r$ *(low-imp.)* $a\sigma\delta/(\beta r)$ *(high-imp.)*	$a\sigma\delta$	$a\sigma\delta$
Main critical parameter(s)	*SE low-imp. source leakage via filters*	*Leakage via cable feed-throughs*	*Leakage via shield imperfections (e.g. slits)*
Evaluation (EN 50147-1)	*SE magnetic field low-imp. source*	*SE electric field high-imp. source*	*SE electric field high-imp. source*

5.2 Evaluation of shielding effectiveness

When assessing the effectiveness of the shield it is advisable to consider both components of an electromagnetic wave, the electric field E and the magnetic field H. Shielding effectiveness can be given in terms of the measured shielding attenuation $A_S = E_0 / E_1$ or $A_S = H_S / H_1$ (both in dB) where E_0 and H_0 are the field strengths at a location without the shield present.

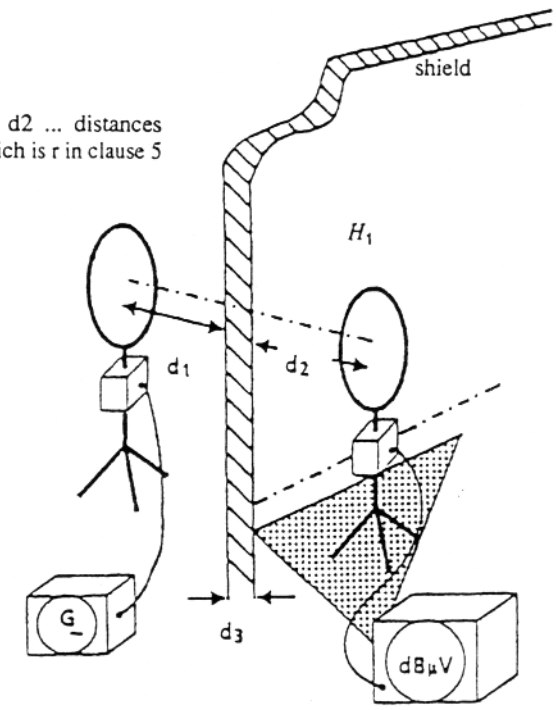


Figure 6 – Shielding attenuation measurement

E_1 and H_1 are the field strengths at the same location with a shield present. The usual measurement arrangement is shown in Figure 6. (This figure is taken from EN 50147-1:1996).

5.3 Shielding components and selection of materials

The shielding against electromagnetic energy depends on the nature of the incident wave (electric field, magnetic field or plane waves). Furthermore, the electrical and magnetic properties of the shielding material as well as selection of sheets or grids play an important role. Both factors cause frequency dependence of the shielding effectiveness. As steel and copper are good conductors, they are typically used for high performance shielded rooms.

For less stringent requirements and for electric fields only up to 50 MHz, wire mesh arrangements are typically sufficient.

Additional material selection consideration may apply such as

a) weight comparison;

b) copper as foil, therefore requiring a supporting structure;

c) self supporting iron sheet;

d) metal braid for limited shielding effect.

Depending on the used material the construction employed to achieve adequate shielding will vary. Several options are available: welded rooms, modular rooms, architectural shielding and wire mesh:

- welded rooms:

  a welded enclosure when properly manufactured/installed, yields to maximum shielding effectiveness. A welded room needs no maintenance under normal operating conditions during its working life, except for moving parts and penetrations;

- modular room:

  a wide variety of modular designs, materials and constructions exist. A well designed and constructed modular room can also provide excellent performance. In general the design must be such the vibrations and temperature cycling have little effect on the contact pressure of the edges and corners of the modular panels, so that RF-current distribution is not disturbed by seams and joints;

- architectural shielding:

  this type of shielding refers to flexible thin layers of metals or foils such as copper and aluminium works well at frequencies well above, say 30 MHz. The method of splicing and overlapping the edges and corners is of great importance to the effectiveness of the shielding;

- rooms with wire mesh:

  this type of shielding is constructed of metallised fabrics (woven and non woven). The method of splicing and overlapping the edges and corners is of great importance to the effectiveness of the shielding. This type of shielding is not recommended above, say 30 MHz. Shielding that uses dissimilar metals which may be subject to galvanic corrosion and those employing screw fixings and tensioners shall be periodically checked for leaks.

5.3.1 Shielded doors and gates

Shielded doors are the most critical penetrations in shielded enclosures. It is generally the weakest element in shielded facilities and the most difficult to maintain due to its moving parts and usage.

To retain high shielding effectiveness requires that the door and frame are strong and precise to maintain the tight tolerances needed to achieve the RF-Seal around the door perimeter. The door leaf is equipped with contact elements to ensure the electrical contact between movable leaf and fixed frame when the door is closed.

Contact elements used as RF gaskets for the door gap are essential to maintain adequate shielding effectiveness. At gaps that are not properly contacted, the current distribution in the shield is disturbed thus causing leakage. With increasing frequency this detrimental effect decreases the total shielding effectiveness of the enclosure.

Typical constructions to obtain good electrical contact between the movable leaf and a fixed frame are given in the following figures.

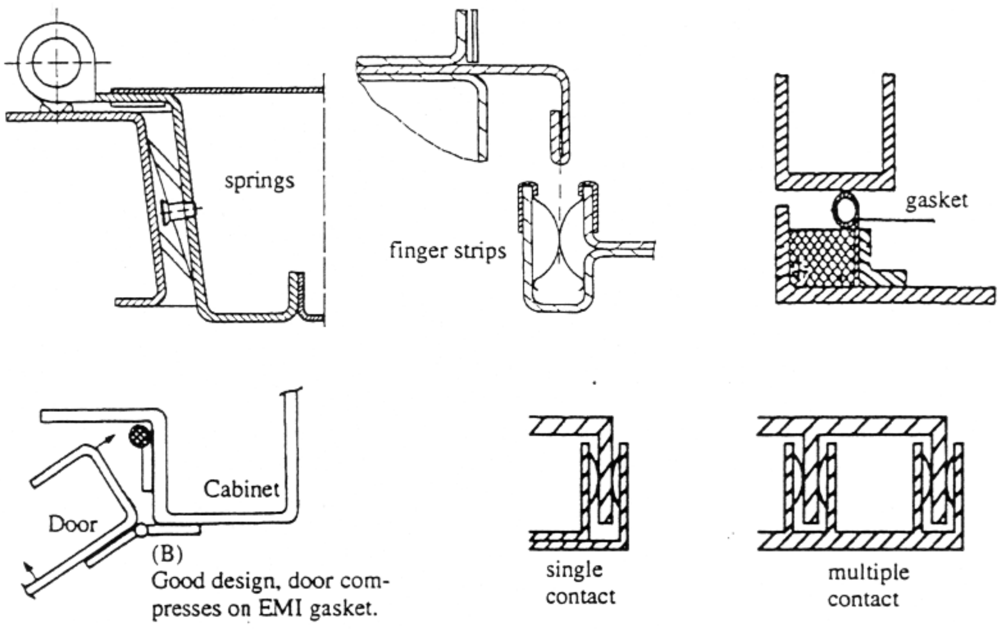


Figure 7 – Examples of door contacts

5.3.2 Honeycomb inserts

Honeycomb inserts consist of a matrix of metal waveguides. Their shielding effectiveness is based on the attenuation behaviour of a waveguide at frequencies below its cut-off frequency and thus depending on the size and length of waveguides. The dimensions of the waveguide are selected such that the cut-off frequency is above the highest frequency the enclosure will be used.

In general the required attenuation can be achieved when the ratio between the length and the maximum width of the waveguide is greater than 5. It is very important to ensure a good electrical contact of the perimeter of the waveguide insert. These shielding elements are primarily used for ventilation as gases can pass through them at high flow rates.

A first estimate of the cut-off frequency f_c can be made by applying the relation $f_c = 1{,}5 / W$ (GHz), where W is the largest cross-sectional dimension of the waveguide in cm.

5.3.3 Shield penetrations

Tube lead-ins are used for gas- and water-supply etc. or for fibre optics or similar. Their shielding effect is based on the waveguide principle. If the tube diameter needs to be larger than permitted for the particular cut-off frequency then the tubes are additionally fitted with waveguide inserts. To maintain the shielding effectiveness at low frequencies it may be necessary to interrupt the possible ground loop via the gas- or water supply. That can be achieved by introduced insulated parts. The contact between shield and penetrating tube shall be ensured by a 360° round good electrical contact.

5.3.4 Cable feed-throughs

If shielded cables have to penetrate trough the wall of shielded room then they shall be passed through the appropriate connectors, ensuring a 360° round good electrical contact of the cable shield and the shield of the enclosure. Shielded cables must have as good shielding effectiveness as the appropriate enclosure (also important during shielding measurement).

5.3.5 Penetration panels

A penetration panel is an exchangeable panel typically used for different combinations of feed through devices. They are an ideal solution for applications requiring different measuring feed throughs.

The connection between enclosure wall and penetration panel shall be ensured by 360° round good electrical contact.

5.3.6 Filter connections

All electrical non shielded lines and cables shall be fed through filters at the location where they enter the shield (see special recommendation of filtering in this EN 50147 series).

Mains filters may show a poor attenuation at frequencies lower than, say 100 kHz, and thus can reduce the overall shielding effectiveness of a shielded enclosure at those frequencies.

5.4 Shielding attenuation values (see Figure 8 measured according to EN 50147-1)

The SE values indicated in Figure 8 represent the state of the art. They have been proved in practice for EMC measurements. In practice larger values might be achieved. The reduction of SE at frequencies > 1 GHz is caused by imperfections and not by property of the shield material. In certain cases, i.e. high ambient field strengths caused by transmitters or the generation of very high field strengths within the shielded room, higher values are required.

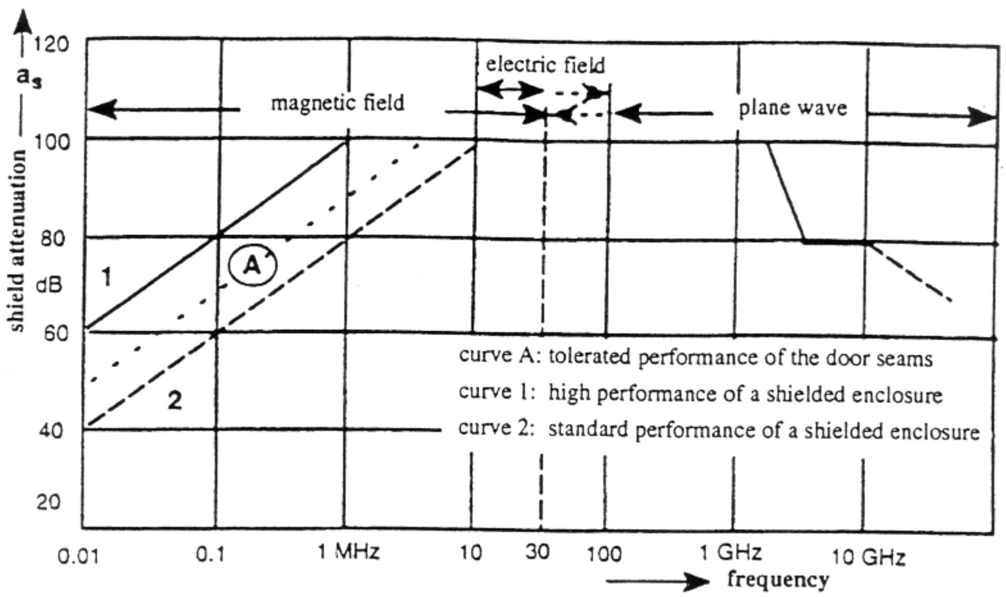


Figure 8 – Shows typical performance values

CALCULATION EXAMPLE (only showing the tendency):

Outside:

Allowed field strength limit 30 dB [µV/m]	at ambient field strength between 30 MHz and 230 MHz (EN 55011 and EN 55022)

Inside:

Produced field strength 140 dB [µV/m] (10 V/m)	Immunity test for industrial environment
Required shielding attenuation = 110 dB	(10 dB to 20 dB shielding attenuation may be achieved by concrete walls of a building, also anechoic material on enclosure walls may reduce the electromagnetic field going through)

Bibliography

[1] S.A. Schelkunoff, Elektromagnetic Waves. Princeton, N.J.: Van Nostrand, 1943

[2] Kaden, H.: Die elektromagnetische Schirmung in der Fernmelde- und Hochfrequenztechnik. Berlin, Göttingen, Heidelberg: Springer-Verlag 1950

[3] EMC textbooks, EMC Journals and EMC Conference Proceedings

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