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Recommendations for shielded enclosures

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
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Central Secretariat: rue de Stassart 35, B - 1050 Brussels

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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

This European Technical Report incorporates by dated or undated references provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. Dated references, subsequent amendments to or revisions of any of these publications apply to this European technical Report only when incorporated in it by amendment or revision. For undated references the latest edition of he publication referred to applies.

- **IEC 50 (161) 19** International Electrotechnical Vocabulary (IEV) Chapter 161 Electromagnetic Compatibility.
- **EN 50147-1**
- **CISPR 22, CISPR 11**

3. Definitions

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.

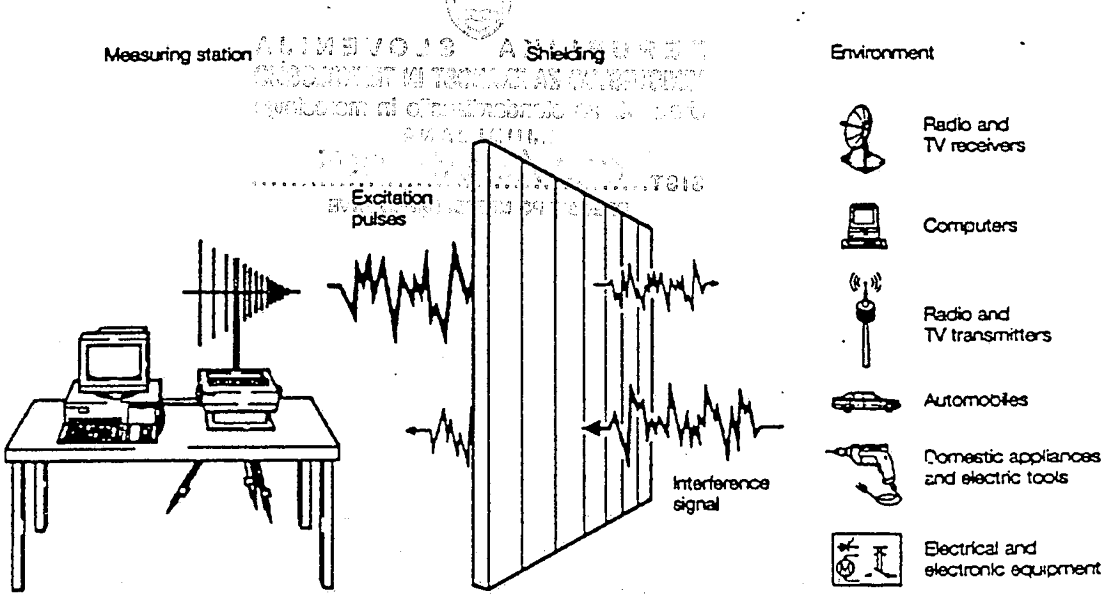

Figure 1: Illustrated set-up for shielding

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 Sec.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:

range I) the near-field region in which $\beta r \ll 1$,
range II) the transition region in which $\beta r \approx 1$, and
range III) the far-field region in which $\beta r \gg 1$.

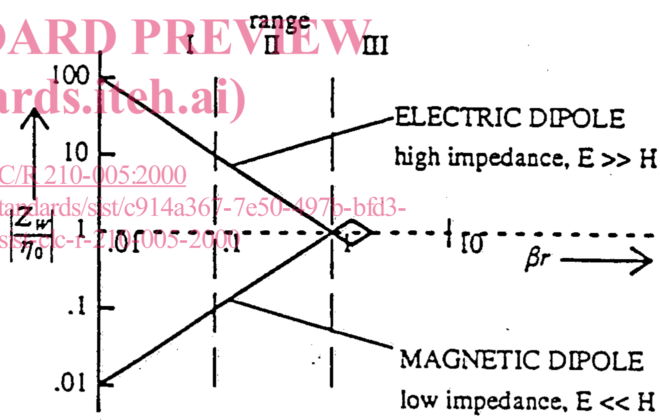

Figure 2: Wave impedance versus distance of the field source

In the far-field (plane wave, free space) the wave impedance is a constant $\eta_0 = 377\ \Omega$. 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 $Z_{wE} \gg \eta_0$, and therefore normally called a high-impedance source. In the near-field Z_{wE} is 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 $\beta r >> 1$ 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. Another source of limitation of the *SE* form the cable feed-throughs.

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, EMC Journals and EMC Conference Proceedings.

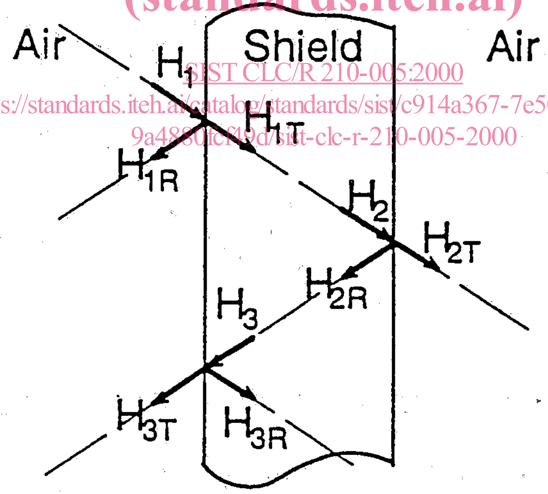

Figure 3: Schematic diagram of the partial reflections (subscript R) and transmissions (subscript T) at the two surfaces of a shield. The incoming field wave is represented by H_I.

According to the Schelkunoff theory, the total attenuation S_T provided by a shield results from three mechanisms, their relation being given by (see Fig.1)

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

where H represents the amplitude of the field component to be shielded. When expressed in dB

$$S_T = S_A + S_R + S_{MR} \qquad (\text{dB}) \qquad (2)$$

These terms are elucidated in Secs. 5.1.1-5.1.3, and numerical examples are given in Sec. 5.1.4.

5.1.1 The absorption loss term $S_A = H_{1T}/H_2$,

i.e. the contribution to S_T as a result of the energy absorption when the field passes once through the shield. S_A can be calculated from

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

where δ is the skindepth of the shielding material, given by

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

and $\omega = 2\pi f$.

Note 1: The conductivity can be written as $\sigma = \sigma_r \cdot \sigma_{Cu}$, 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 $\mu = \mu_r\mu_0$, where $\mu_0 = 4\pi \cdot 10^{-7}$ H/m and μ_r the relative permittivity of the shield. Expressing the frequency in MHz, δ can be written as

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

Note 2: S_A does not depend on the distance between source and shield, it only depends on the shield material parameters t, σ, μ and the frequency f. From Eq. (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 Section 5.

a) Near field ($\beta r << 1$):

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

$$S_R = S_{RE} = \frac{\sigma\delta}{4\sqrt{2}} \cdot \frac{\eta_0}{\beta r} \tag{6}$$

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

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

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 ($\beta r >> 1$):

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

$$S_R = \frac{\sigma\delta}{4\sqrt{2}} \eta_0 \tag{8}$$

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

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

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 Eq. (6) applies. Therefore, in the aforementioned estimates the following additional condition shall be used:

$$\text{If} \quad S_{RH}S_{MR} < 1 \quad \text{then} \quad S_{RH}S_{MR} = 1 \tag{10}$$

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), $\sigma_r = 0.1$ (e.g. that of iron) and $\mu_r = 200$ (e.g. the minimum μ_r for cold rolled steel) and a magnetic dipole as the source of the field.

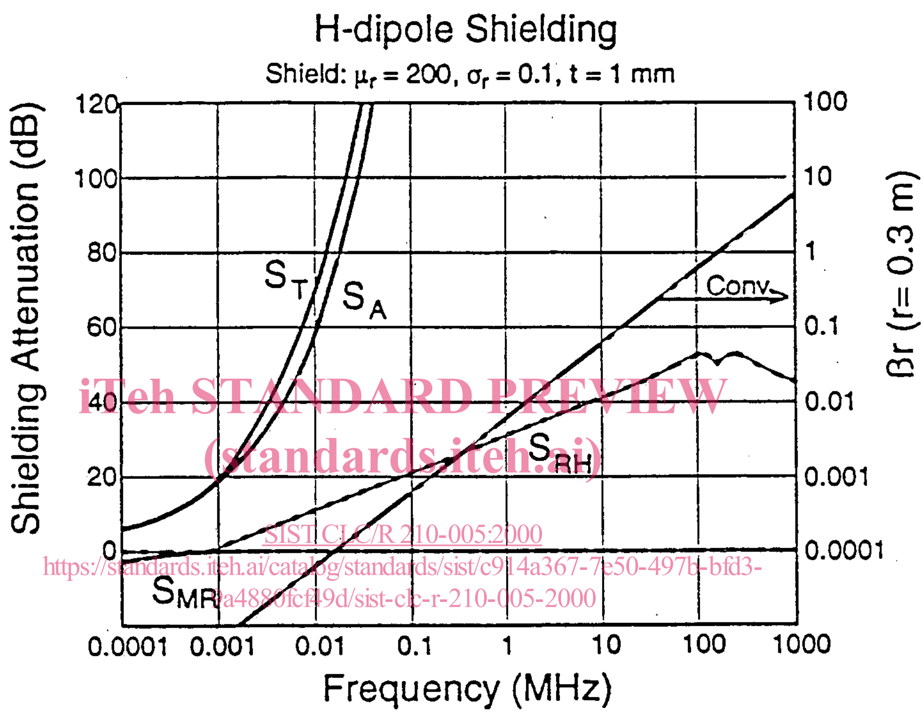

Figure 4: S results calculated for a low-impedance magnetic field source. The curve labelled 'conv' allows conversion of a frequency value into a βr value, taking $r = 0.3$ m.

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 $\mu_r >> 1$. 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 Sec. 5.3.1. The values of S_T in Figure 4 just comply with Curve 2, the standard performance curve in Fig. 8 in Section 5.4.

Assuming a much large value of r, say r = 5 m, $\beta r = 1$ at f ≈ 10 MHz. An example of results of $S(f)$, assuming additionally that t = 1 mm, $\sigma_r = 0.6$ (e.g. aluminium), and $\mu_r = 1$, is given in Figure 5