

# Analysis of the Shielding Effectiveness of Several Magnetic Shields

Diako Azizi, Hosein Heydari and Ahmad Gholami

**Abstract**—Today with the rapid growth of telecommunications equipment, electronic and developing more and more networks of power, influence of electromagnetic waves on one another has become hot topic discussions. So in this article, this issue and appropriate mechanisms for EMC operations have been presented. First, a source of alternating current (50 Hz) and a clear victim in a certain distance from the source is placed. With this simple model, the effects of electromagnetic radiation from the source to the victim will be investigated and several methods to reduce these effects have been presented. Therefore passive and active shields have been used. In some steps, shielding effectiveness of proposed shields will be compared. It should be noted that simulations have been done by the finite element method (FEM).

**Keywords**—Electrical field, field distribution, finite element method, shielding effectiveness

## I. INTRODUCTION

SHIELDING is a fundamental step in establishing or improving the electromagnetic compatibility of active and of passive devices. The physical principles which form the base of shielding depend on the frequency range: For static and low frequency electric fields the Faraday cage, i.e., a grounded conducting net, is used which may encounter apertures up to a certain size. The electric charges on this metallic net serve as the end points for the lines of force of the divergence-type electric field. For low-frequency magnetic fields, the induced eddy currents within the shielded enclosure material are responsible for the shielding effect. Thus, high values of the product of conductivity and permeability as well as the avoidance of resistances for the eddy currents by apertures, slits, etc., are recommended. For high-frequency and transient electromagnetic fields, the shielding principle and, consequently, the shield design are more complex. Since almost every realistic shield must have apertures, electromagnetic radiation may penetrate into the interior and interfere with the shielded device, or even cause resonances within the shielded domain. Due to these very different kinds of shielding mechanisms, different measures to quantify the

overall efficiency of a shielding structure are in use [1]. The common definitions for low frequency electric and magnetic fields base on the values of the electric and magnetic field intensity within an empty shielding enclosure and are referred to as the electric and magnetic shielding effectiveness, respectively [2]. For the electromagnetic case, IEEE Standard 299.1997 provides a method applicable to relatively large enclosures while measuring the shield's insertion-loss by using suitable broad-band antennas [3].

One problem with these definitions for high-frequency problems is addressed by finding that point or these points within the shielded domains, which are supposed to be *typical* for the total interior of the shield. Moreover, the influence of a load on the shielding effectiveness has to be clarified. Another question arises for problems where the IEEE Standard method [4] is not applicable, e.g., if the enclosure dimensions are too small. Finally, shielding effectiveness should be definable for the transient case as well.

Therefore at first the field distribution in two cases with and without shield must be provided. Different methods have been used to calculate the radiation of electromagnetic fields [3], [5]. The main difficulty is that the surrounding medium is highly inhomogeneous. The finite element method allows accurate modeling of complex structures with arbitrary shaped regions and takes easily into account inhomogeneous materials.

In this paper using the proposed method, the shielding effectiveness of different modes have been presented and compared.

## II. DEFINITIONS OF THE SHIELDING EFFECTIVENESS

The common definitions of the electric and magnetic shielding effectiveness at an arbitrary point  $q$  within the shielded domain are given by [2]:

$$SE_e|_q = 20 \log_{10} \frac{|\vec{E}^{unshield}|_q}{|\vec{E}^{shield}|_q} \quad dB \quad (1)$$

$$SE_m|_q = 20 \log_{10} \frac{|\vec{H}^{unshield}|_q}{|\vec{H}^{shield}|_q} \quad dB \quad (2)$$

respectively. The numerators in (1) and (2) represent the amplitudes of the time-harmonic electric and magnetic field intensities, measured at  $q$  in the absence of the shield, while the denominators contain their values in the shielded case at the same locations. The advantage of these definitions is that they are relatively easy to realize; however, they are intended mainly for low-frequency electric and magnetic fields. In the

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high-frequency case, i.e., when the dimensions of the shield are comparable or larger to the wave-length, the attenuation of the *electromagnetic* field (rather than of the electric and magnetic fields alone) has to be considered. To come to a physically meaningful SE definition, suppose that the shield is not empty but (partly) filled with a test load, and define the special shielding measure  $a_p$  as the ratio of the time-averaged electromagnetic power received by the unshielded load to that one received by the shielded load, each for the same incident field, as:

$$a_p = 10 \log_{10} \frac{p_{\text{unshield}}}{p_{\text{shield}}} \quad \text{dB} \quad (3)$$

This definition considers the attenuation of the electromagnetic field induced by the shield *and* the influence of the (special) test load. The main drawback is obviously that a measurement of  $a_p$  would generally require a considerable expenditure. Moreover,  $a_p$  would be valid only for this special load, and it had to be remeasured or recalculated for any new one. To come to a meaningful and practicable definition which characterizes the shielding ability of the enclosure itself and which is still based on this  $a_p$ , consider a spherical load with radius  $r_L$  which is concentrically located around the point  $q$ . As shown in Appendix A, in the limiting case  $r_L \rightarrow 0$  and for an incident plane wave the special shielding measure  $a_p$  passes into the electromagnetic shielding effectiveness at the point  $q$ , defined by:

$$SE_{em}|_q = 10 \log_{10} \frac{2}{\frac{|\vec{E}^{shield}|_q^2}{|\vec{E}^{unshield}|_q^2} + \frac{|\vec{H}^{shield}|_q^2}{|\vec{H}^{unshield}|_q^2}} \quad (4)$$

Hence, the electromagnetic shielding effectiveness is *calculated* as a simple combination of the values of the electric and magnetic shielding effectiveness, measured at the point  $q$ . Therefore, it is easily determinable even for relatively small enclosures. Physically, the electromagnetic shielding effectiveness represents the shield-induced reduction of electromagnetic power delivered to an infinitesimal load. Note that from (4) it follows:

- $SE_{em} = SE_e = SE_m$ , if  $SE_e = SE_m$ ;
- $SE_{em} = SE_e + 10 \log_{10} 2 \text{ dB}$ , if  $SE_m \ll SE_e$ ;
- $SE_{em} = SE_m + 10 \log_{10} 2 \text{ dB}$ , if  $SE_e \ll SE_m$ .

### III. ELECTROMAGNETIC MODELS [6]

Ampere's law is the main part to derive electromagnetic system equation.

$$\nabla \times H = J + \frac{\partial D}{\partial t} = \sigma E + \sigma v \times B + J^e + \frac{\partial D}{\partial t} \quad (6)$$

Where:

- $E$  is the electric field intensity
- $D$  is the electric displacement or electric flux density
- $H$  is the magnetic field intensity
- $B$  is the magnetic flux density
- $J$  is the current density

- $J^e$  is the externally generated current
- $\sigma$  is the electrical conductivity
- $v$  is the velocity

Time variant-harmonic field's effect can be introduced by equations (2) and (3):

$$B = \nabla \times A \quad (7)$$

$$E = -\nabla V - \frac{\partial A}{\partial t} \quad (8)$$

Ampere's law is rewritten by equations (2) and (3) Combining with constitutive relationships  $B = \mu_0(H + M)$  and  $D = \epsilon_0 E + P$ , as:

$$\begin{aligned} (j\omega\sigma - \omega^2\epsilon_0)A + \nabla \times (\mu_0^{-1} \nabla \times A - M) \\ - \sigma v \times (\nabla \times A) + (\sigma + j\omega\epsilon_0)\nabla V = J^e + j\omega P \end{aligned} \quad (9)$$

In which  $\omega$ ,  $\epsilon_0$ ,  $\mu_0$ ,  $M$  and  $P$  respectively refer to Angular frequency, Relative permittivity, Relative permeability, magnetization vector and electric polarization vector.

In the case of 2-dimensional-plane, there are no variations in  $z$ -direction, so the electric field is parallel to  $z$ -axis, therefore  $\nabla V$  is written as  $-\Delta V/L$ , where  $\Delta V$  is the potential difference over the distance  $L$ . Now these equations are simplified to:

$$\begin{aligned} -\nabla \cdot \left( \mu_0^{-1} \nabla A_z - \begin{bmatrix} -M_y \\ M_x \end{bmatrix} + \sigma v \cdot \nabla A_z + (j\omega\sigma - \omega^2\epsilon_0) \right) A_z \\ = \sigma \frac{\Delta V}{L} + J_z^e + j\omega P_z \end{aligned} \quad (10)$$

In the ax-symmetric case, another form of the electric potential gradient has been used ( $\nabla V = \frac{-V_{loop}}{2\pi r}$ ) as the electric field is only present in the azimuthally direction. The above equation, in cylindrical coordinates, becomes:

$$\begin{aligned} -\left( \left[ \frac{\partial}{\partial r} \frac{\partial}{\partial z} \right] \left[ r\mu_0^{-1} \left[ \frac{\partial u}{\partial r} \right] + \mu_0^{-1} \begin{bmatrix} z \\ 0 \end{bmatrix} u - \begin{bmatrix} M_z \\ -M_r \end{bmatrix} \right] \right) \\ + r\sigma \left( v \cdot \left[ \frac{\partial u}{\partial r} \right] \right) + r(\sigma j\omega - \omega^2\epsilon_0)u + 2\sigma V_r u \\ = \sigma \frac{V_{loop}}{2\pi r} + J_\phi^e + j\omega P \end{aligned} \quad (11)$$

The dependent variable  $u$  is the nonzero component of the magnetic potential divided by the radial coordinate  $r$ , so that:

$$u = \frac{A_\phi}{r} \quad (12)$$

The application mode performs this transformation to avoid singularities on the symmetry axis.

### IV. SIMULATION RESULTS

In this section, the case study has been presented. The depicted cable in Fig.1 has been assumed as the EMI source ( $j=3 \text{ A/mm}^2$ ,  $f=50\text{Hz}$ ,  $r=10 \text{ Cm}$ ). Similar cable that is surrounded with standard magnetic Iron shield (thickness=1cm) has been assumed as victim. Fig.2 shows the magnetic field distribution.

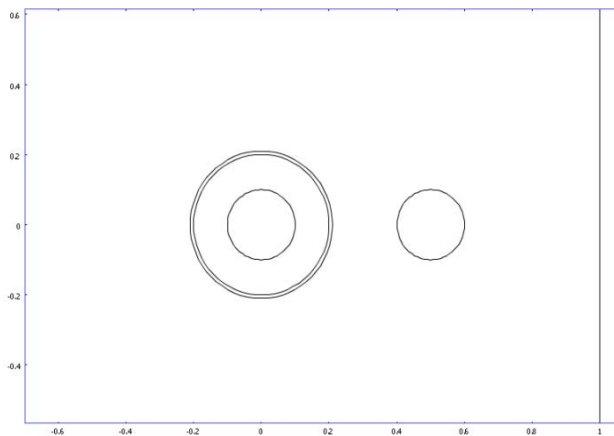


Fig. 1 primary case study

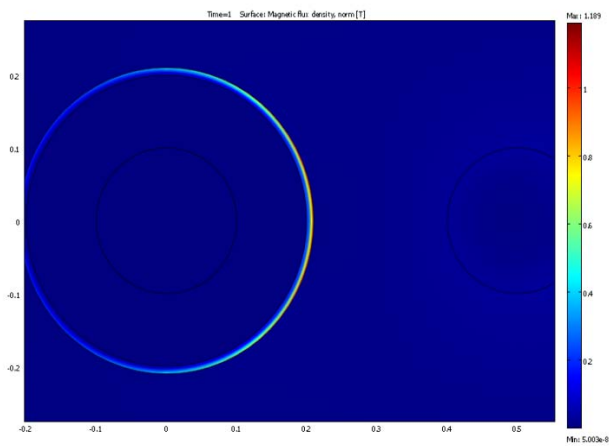


Fig. 2 Magnetic field distribution of primary case study (T)

Fig. 3 shows the magnetic shielding effectiveness distribution in the primary case study. Then in the Fig.4 the magnetic shielding effectiveness distribution with the injecting 3th harmonic (magnitude=1/3 p.u) has been presented. It is so clear that shielding effectiveness has been decreased intensively due to magnetic saturation of shield. Fig.5 shows the shielding effectiveness in the case that permeability of shield increased as 10 times.

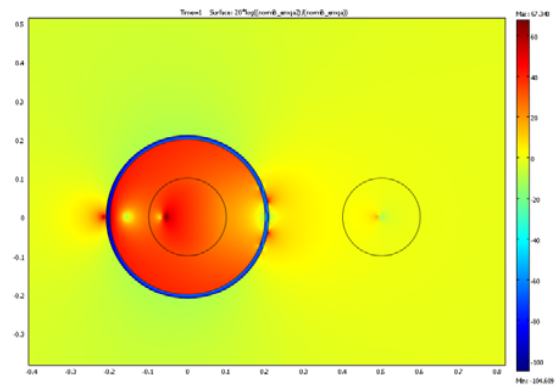


Fig. 3 Magnetic shielding effectiveness distribution in the primary case study (dB)

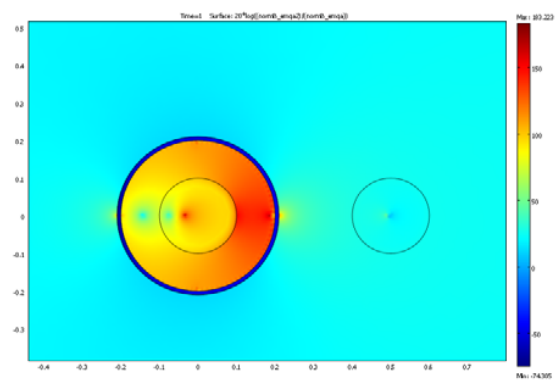


Fig. 4 The magnetic shielding effectiveness distribution with the injecting 3th harmonic (dB)

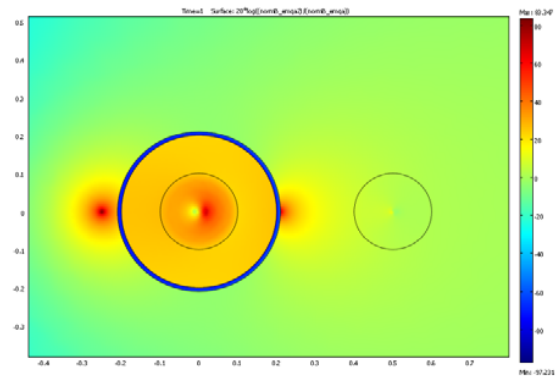


Fig. 5 The shielding effectiveness in the case that permeability of shield increased as 10 times (dB)

In the Fig. 6 the effect of none conducting of shield is considered. It is obvious that SE has been decreased.

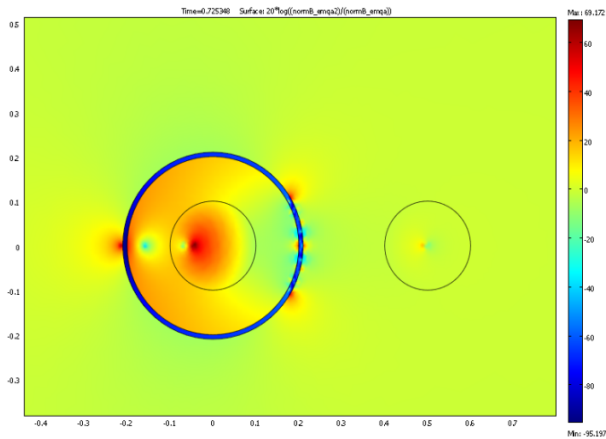


Fig. 6 The shielding effectiveness in the case that electric conductivity of shield decreased as 0 (dB)

In this case, the SE decreased since in the conducting shield, a conductor loop is placed around the device so that the incident B field penetrates the surface bounded by the loop, thereby inducing, according to Faraday's law, a current in the loop and associated magnetic flux. This induced magnetic flux has a reference polarity that counteracts with the original magnetic field, and so the net magnetic field in the area bounded by the loop is reduced, so the SE in the case of conducting shield increased.

At the next step the effect of double shielding will be presented. Fig.7 shows the  $SE_m$  for double shielded victim. Fig.8 presents the  $SE_m$  for the case that both of victim and source have been shielded and Fig.9 shows  $SE_m$  for smaller shield.

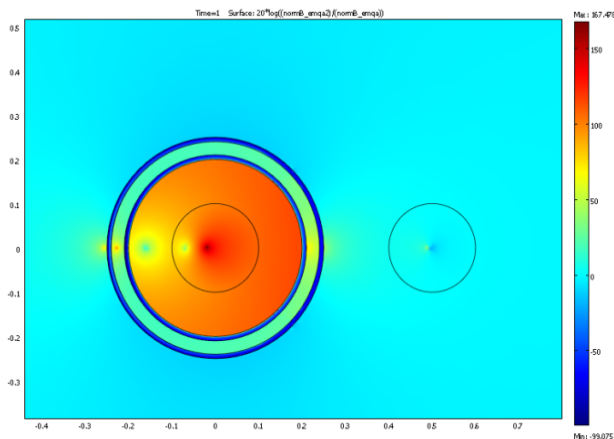


Fig. 7  $SE_m$  distribution for double shielded victim (dB)

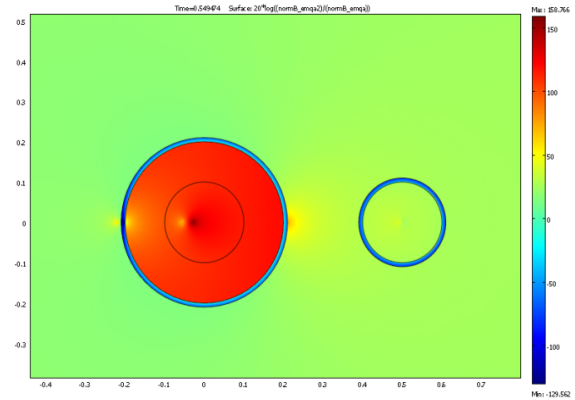


Fig. 8  $SE_m$  for the case that both of victim and source have been shielded (dB)

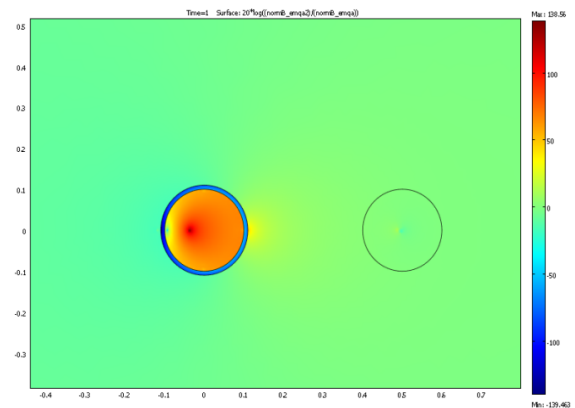


Fig. 9  $SE_m$  for smaller shield (dB)

Fig. 10 depicts the incomplete shield and Corresponding  $SE_m$ . It is so clear that  $SE_m$  decreased intensively.

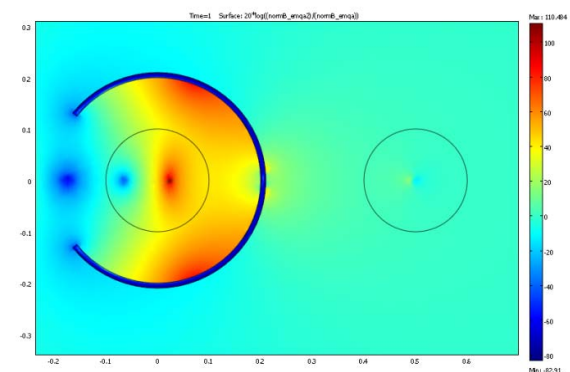


Fig. 10  $SE_m$  for incomplete shield (dB)

## V. CONCLUSION

- Saturation of shield courses that  $SE_m$  decreased intensively
- Increasing in frequency of harmonics enhances the  $SE_m$
- Conducting shield acts as active shield so  $SE_m$  increases
- Double shielding, increases the  $SE_m$  severely
- Incomplete shield, reduces the  $SE_m$



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