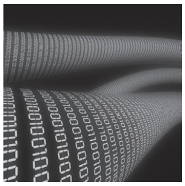

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# Shielding of the electromagnetic field in the range of small frequencies as the factor for ensuring compatibility in electronic transportation systems

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## ABSTRACT

Security systems are operated in diversified weather conditions and in various surrounding electromagnetic environments, which may be the cause of the occurrence of interferences. The article presents fundamental the principles of shielding of electromagnetic field in the range of small frequencies.

**KEYWORDS: field, small frequencies, compatibility**

## 1. Introduction

The main purpose of transport is to transfer people and cargo. The security of transport is the property of the transport process realized (the process of transferring people and/or cargo) [2,6,10]. This process should be characterized by a high level of reliability and security. The measure of transport security is the trust that the elements of the transport process will remain intact during its realization apart from those changes that are the result of the natural processes of tear and wear [6,7]. To ensure an appropriate level of safety, it is essential to use security systems. Whose objective is an increase of the security of people and cargo in transport [12,20,21]. Security systems are those systems whose objective is to detect threats that occur in the transport process (both for stationery and moving objects) [15]. Those systems are more and more frequently used in the transport process, where they ensure security:

- to people (e.g. security systems installed in permanent facilities railway stations);
- to people and cargo transported in system;
- to cargo transported system; in connection with a GPS system, they can monitor the state of the cargo and the route of a given means of transport [4,5,9,15,18].

Security systems are operated in diversified weather conditions and in various surrounding electromagnetic environments, which may be the cause of the occurrence of interferences [1,8,11]. Security systems installed in the railway area are particularly exposed to the impact of electromagnetic interferences, whose source is moving objects (traction vehicles) and the whole electric and electronic infrastructure of the railway area: i.e. traction power supply, electrical power transformer stations, rail traffic control systems, telecommunication systems [16,17,20,21]. A high level of interferences may be the cause of an occurrence of interference in the operation of digital systems and microprocessor systems that control and security systems are composed of (e.g. a burglary and assault signalling system) [19]. In the railway area, there occur interferences with various frequency ranges, including interferences in the range of small frequencies: ELF (5 – 2000) Hz and VLF (2 – 100) kHz.

## 2. The principles of shielding of electromagnetic field in the range of small frequencies

The shield constitutes a metallic separation of two areas of space. It is used to decrease the degree of the transfer of electric and magnetic fields from one area to another area. Shields can be used to limit the space of the occurrence of electromagnetic fields if they surround the sources of interferences, or to maintain electromagnetic radiation outside a certain area [3,5]. The *effectiveness of shielding*, which is determined as a relation of the value of the field intensity in a given space without a shield to the field intensity after an introduction of a shield, is the basic parameter that defines the properties of a shield. The notion of *shield dampening S* is sometimes used instead of the effectiveness of shielding. This parameter is determined in decibels in accordance with the following dependence [3,13]:

$$S = 20 \log (P_{be} / P_{ze}) \qquad (1)$$

where:

$P_{be}$ – field intensity without a shield;

$P_{ze}$ – field intensity with a shield.

In the case of an electric field or a coupled field, the effectiveness of shielding is expressed by means of the following formula [3,13]:

$$S_E = 20 \log (E_{be} / E_{ze}) \qquad (2)$$

where:

$E_{be}$ and $E_{ze}$ – intensities of the electric field with and without a shield.

In relation to the magnetic field, by analogy [13]:

$$S_H = 20 \log (H_{be} / H_{ze}) \qquad (3)$$

where:

$H_{be}$ and $H_{ze}$ – intensities of the magnetic field with and without a shield.

As shown in fig. 1, two types of losses occur when an electromagnetic wave falls on a metal surface. Wave $F_1$ that comes from the source of radiation is in part reflected from the surface of the shield, and it creates wave $R$, while its transferred part $A$ (not reflected) is dampened when going through the medium (losses of absorption), which it leaves as wave $F_2$.

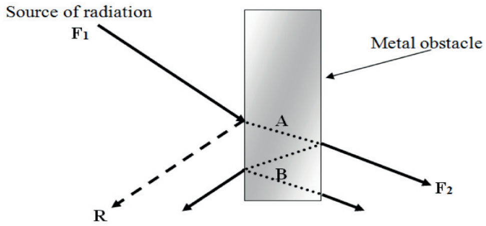

**Fig. 1. Principle of shielding of an electromagnetic wave through a metal obstacle [own study]**

The total effectiveness of shielding of a material is equal to the sum of the measurements of relative losses of absorption $A$, reflection losses $R$ and correction coefficient $B$ that takes into consideration multiple reflections in thin shields – fig. 2. The total shielding effectiveness can be written as follows:

$$S = A + R + B \qquad (4)$$

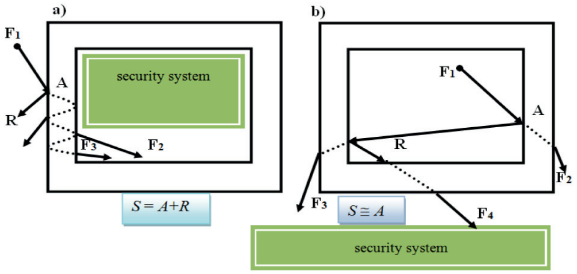

**Fig. 2. Principle of shielding of the source of radiation F1: a) located outside the shield, b) located inside the shield [3]**

Correction coefficient $B$ (of multiple reflection) can be omitted if absorption losses $A$ are greater than 10 dB. From a practical point of view, coefficient B is omitted for electric fields and flat waves. The effectiveness of shielding is explained in the following manner. Currents that are inducted in the shields, which are generated as a result of the activity of interfering fields, generate their own fields, which aim at levelling the original fields. The determination of shielding effectiveness consists in providing information as to by how much the intensity of the magnetic or electric field decreased owing to the use of a shield. In the case of an electromagnetic wave that falls on a well conducting surface, the reflection angle of this wave is the incidence angle. On the surface, the component tangent of the electric field intensity and normal component of the magnetic fields are equal to zero. In practical cases, reflection losses $R$ in a close field for flat waves can be defined with the following formula [3,13,14]:

$$R = 168 - 10 \log(\mu_r \cdot f / \sigma_r) \qquad (5)$$

where:

$\mu_r$ – relative magnetic permeability,

f – frequency (MHz),

$\sigma_r$ – relative conductivity of the material of the shield.

In the case of electric fields, a greater part of the incident wave is reflected and it is only its scanty part that penetrates a well conducting shield. For magnetic fields, a greater part of incident wave goes to the shield, where it undergoes a multiple reflection. For the magnetic field in the shield, the correction coefficient $B$ of multiple reflection (in dB) is expressed with the following formula [3]:

$$B = 20 \log[1 - \exp(-2e/d)] \qquad (6)$$

where:

e - shield thickness,

*d* - penetration depth of magnetic field

The penetration depth of the field d is defined with the following formula [3]:

$$\delta = \sqrt{\frac{2}{2\pi f \mu \sigma}} \qquad (7)$$

where:

f - frequency,

m - absolute magnetic permeability,
s - conductivity.

The correction coefficient *B* is a negative number. This show that with very thin shields, the effect of multiple reflection considerably weakens the total losses of absorption. Losses in reflections are the greater the smaller the impedance of the shield is. The impedance of the shield can be reduced through the use of materials with high conductivity and small magnetic permeability. Absorptive dampening *A* expressed in decibels can be easily calculated when the field penetration depth is known [13].

$$A = 8{,}7\ e/d \tag{8}$$

where:
e –shield thickness in any units,
d - field penetration depth in the same units as e.

When propagated in the shield, a part of the wave which undergoes dampening changes its energy into heat. A great effectiveness of shielding by absorption is obtained by using well conducting materials with a high magnetic permeability e.g. iron. Absorption losses depend on the frequency, shield thickness and kind of material.

# 3. Results of the measurements of electromagnetic fields with various shields

In the experimental part of the article, the parameters were examined of different shields which were used to reduce the environmental impact of radiation generated by selected electronic devices. Shields were examined that were made from various materials, both single-layer and multi-layer ones. The results of the measurements of magnetic field induction *B* and electric field intensity *E*, at the housing of the generator examined are presented in tables 1 and 2.

**Table 1. Values of magnetic field induction B at the housing of the device**

| Measurement location | Value of magnetic field induction ELF B[μT] | Value of electric field induction VLF B[nT] |
|---|---|---|
| Left side | 12 – 192 | 1.7 – 113 |
| Right side | 3 – 15 | 0.6 – 4.1 |
| Back | 3.5 – 6 | 5.9 – 9.4 |
| Front | 7.4 – 82 | 14 – 128 |

**Table 2. Values of electric field intensity E at the housing of the device**

| Measurement location | Value of electric field intensity ELF [V/m] | Value of electric field intensity VLF [V/m] |
|---|---|---|
| Left side | 40 – 220 | 0.3 |
| Right side | 5.7 – 99 | 0.3 |
| Back | up to 750 | 0.3 |
| Front | 4.7 – 22.4 | 0.3 |

The maximum and minimum values that occur on the surfaces examined are given in the tables above. The measurements were carried out with single-layer shields made from various materials. The diagram of the mutual location of the shielded device in relation the shield is presented in fig. 3. The following materials were used for one-side shielding - steel metal sheet with thickness h = 1.5 mm; - one-side laminate with copper layer thickness $h_{Cu}$ = 35μm; two-side laminate with copper layer thickness $h_{Cu}$ = 70μm.

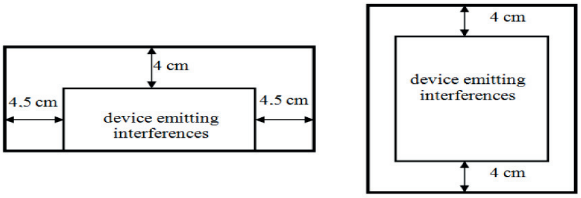

**Fig. 3. Location of the device that generates electromagnetic field in the shield [own study]**

The results of the measurement of the distribution of magnetic field induction *B* in the function of distance *d* from a shield made from steel metal sheet are presented in fig. 3. As seen in fig. 4, magnetic field induction diminishes quite considerably with an increase of the distance from the device.

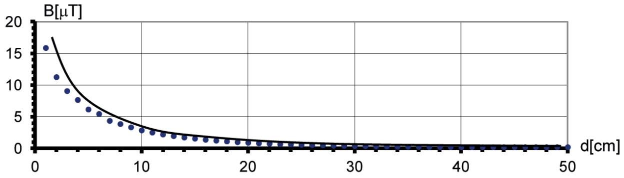

**Fig. 4. Distribution of magnetic field induction B [μT] in the function of distance d [cm] at the point of the maximum intensity of this field by the device examined [own study]**

In order to determine the directions of the maximum radiation, omnidirectional measurements were made in relation to the geometrical centre of the housing of the shielded device – fig. 5.

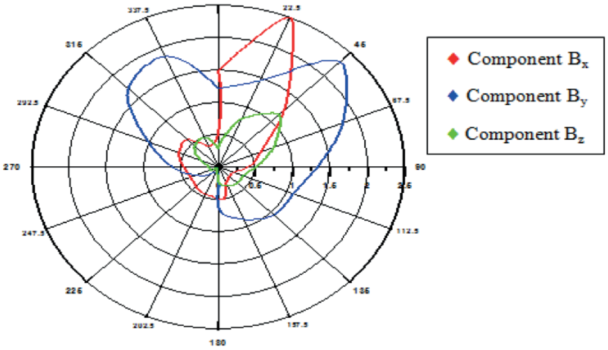

**Fig. 5. Omnidirectional characteristics for the individual components $B_x$, $B_y$, $B_z$ of magnetic field induction B[μT] for ELF frequency range in the case of a steel shield [own study]**

**Table 3. Shielding effectiveness of magnetic field in ELF range for single shields**

| Type of shield | S [dB] | | | |
|---|---|---|---|---|
| | 0° | 90° | 180° | 270° |
| Steel metal sheet shield (h = 1.5 mm) | 8.26 | 5.9 | 1.21 | 3.21 |
| Shield from one-side laminate h(Cu) = 35 µm | 1.67 | -1.19 | -2.31 | -1.11 |
| Shield from two-side laminate h(Cu) = 70µm | 2.56 | -2.24 | -4.05 | 0 |

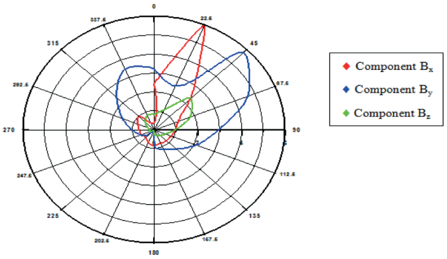

**Fig. 6. Omnidirectional characteristics for the individual components $B_x$, $B_y$, $B_z$ of magnetic field induction B[µT] for ELF frequency range in the case of one-side laminate shield (thickness of copper layer h = 35 µm, dielectric layer depth h = 1.5 mm) [own study]**

**Table 4. Shielding effectiveness of magnetic field in VLF range for single shields**

| Type of shield | S [dB] | | | |
|---|---|---|---|---|
| | 0° | 90° | 180° | 270° |
| Shield from steel metal sheet (h = 1.5 mm) | 13.25 | 6.02 | 2.92 | 1.58 |
| Shield from one-side laminate h(Cu) = 35 µm | 4.31 | 0.92 | 0 | 0 |
| Shield from two-side laminate h(Cu) = 70µm | 8.15 | 0 | 1.34 | 1.58 |

**Table 5. Shielding effectiveness of electric field in ELF range for single shields**

| Type of shield | S [dB] | | | |
|---|---|---|---|---|
| | 0° | 90° | 180° | 270° |
| Shield from steel metal sheet (h = 1.5 mm) | 2.83 | 13.17 | -3.552 | -2.83 |
| Shield from one-side laminate h(Cu) = 35 µm | 1.79 | 12.25 | -6.58 | -1.24 |
| Shield from two-side laminate h(Cu) = 70µm | 2.02 | 4.37 | 3.55 | -4.65 |

**Table 6. Shielding effectiveness of electric field in VLF range for single shields**

| Type of shield | S [dB] | | | |
|---|---|---|---|---|
| | 0° | 90° | 180° | 270° |
| Shield from steel metal sheet (h = 1.5 mm) | 8.52 | 0 | 0 | 0 |
| Shield from one-side laminate h(Cu) = 35 µm | 8.52 | 0 | 0 | 0 |
| Shield from two-side laminate h(Cu) = 70µm | 8.52 | 0 | 0 | 0 |

After the examination of the effectiveness of single-layer shields, measurements were made of fields around the shielded device with the aid of two and then three layers of various materials. Fig. 7 presents intervals between the successive layers of shields.

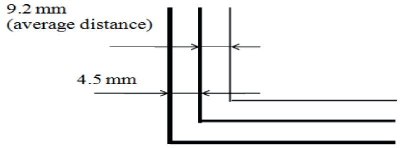

**Fig. 7. Distances between layers in a multi-layer shield [own study]**

Tables 7 include the values of the received dampening *S* of magnetic and electric fields for two-layer shields.

**Table 7. Shielding effectiveness of magnetic and electric fields for a shield which consists of steel metal sheet and one-side laminate**

| Type of field | Frequency range | S [dB] | | | |
|---|---|---|---|---|---|
| | | 0° | 90° | 180° | 270° |
| Magnetic field | ELF | 9.42 | 5.84 | 0.39 | 3.44 |
| | VLF | 13.25 | 4.44 | 0 | 0 |
| Electric field | ELF | -8.11 | -7.39 | -10.95 | -12.2 |
| | VLF | 8.52 | 0 | -7.36 | 0 |

# 4. Conclusion

Investigations into the effectiveness of shielding of unintentional electromagnetic fields emitted by selected electronic devices were conducted for the so-called small ELF and VLF frequencies. A division into such ranges is the result of the instruments that were used for the measurements. It is also used in standards for the protection against a negative impact of electromagnetic fields. Diagrams 8 - 9 present the shielding effectiveness of the magnetic field and the electric field for individual frequency ranges. The types of the shield used were marked in the figures with digits 1-7:
1. steel sheet shield; 2. single-side laminate shield; 3. double-side laminate shield; 4. multi-layer shield: steel sheet, single-side laminate; 5. multi-layer shield: single-side laminate; double-side laminate; 6. multi-layer shield: steel sheet, double-side laminate; 7. multi-layer shield: steel sheet, single-side laminate; double-side laminate.

A considerable difference can be observed as regards the shielding effectiveness between the electric and magnetic fields. The results obtained during investigations confirm the dependence of the shielding effectiveness from the type of materials used and the design solutions of the shields. It is much easier to shield an electric field than a magnetic one. A sufficient shielding effectiveness of the electric field was established in the case of single-layered shields made from all the materials tested. Diagrams 8 present the values of the shielding effectiveness of the electric field in ELF and VLF ranges for all the shields tested. In the majority of cases, the shielding effectiveness accepts positive values, which proves an adequate level of damping. It is only in two cases in the ELF frequency range, that negative values of damping *S* were found. This concerns multi-layer shields made from steel sheet and single-side laminate as well as steel sheet and single-side and double-side laminate. As expected, steel sheet proved to be the most effective material that shields the magnetic field. The shielding effectiveness of the magnetic field can be improved by using a shield with a large magnetic permeability coefficient m or by increasing the thickness of the sheet used for the shield. As can be seen in Diagrams 9 the shielding effectiveness values are positive in both ranges of ELF and VLF frequencies. In accordance with the theory, a greater shielding effectiveness is found for the selected cases in the VLF frequency, i.e. for greater frequencies.

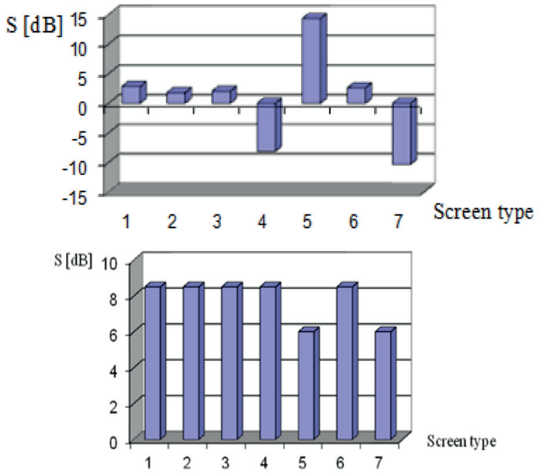

**Fig. 8. Shielding effectiveness S [dB]: electric field for VLF range, electric field for ELF range [own study]**

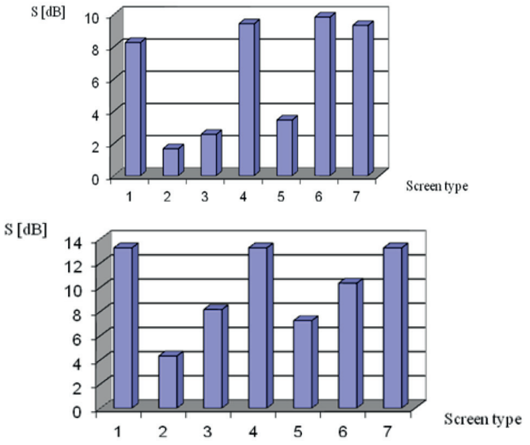

**Fig. 9. Shielding effectiveness S [dB]: magnetic field for ELF range, magnetic field for VLF range [own study]**

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