State Institution “Institute of Technical Problems of Magnetism
of the National Academy of Sciences of Ukraine”
Kharkiv, Ukraine

Discrete Optimization of Grid Shield for Overhead Line Magnetic Field Mitigation

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of the National Academy of Sciences of Ukraine

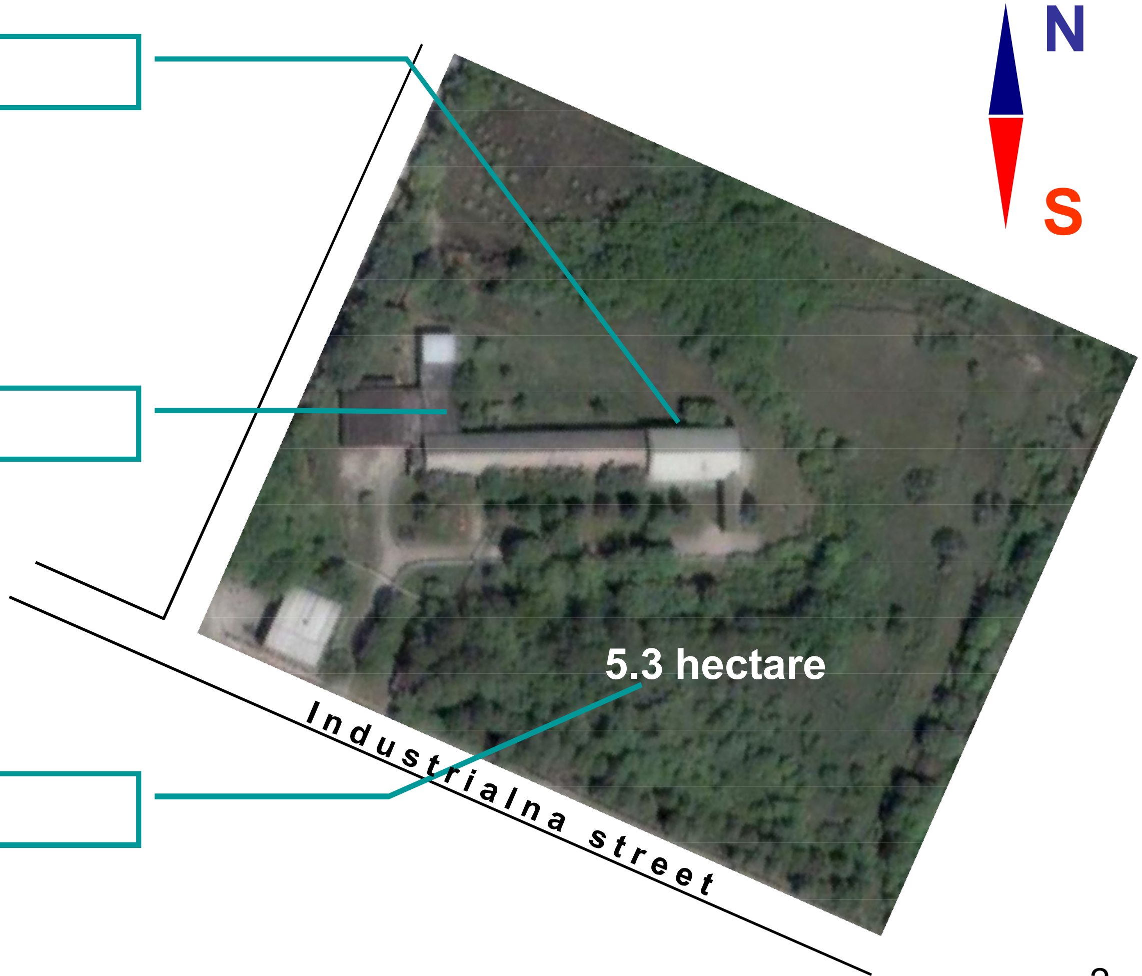
Location: Industrialna st., 19, 61106, Kharkiv, Ukraine.

Site: http://itpm.org.ua/en/

Magnetomeasuring workbench

Systems of current supply

Technological ground-plot

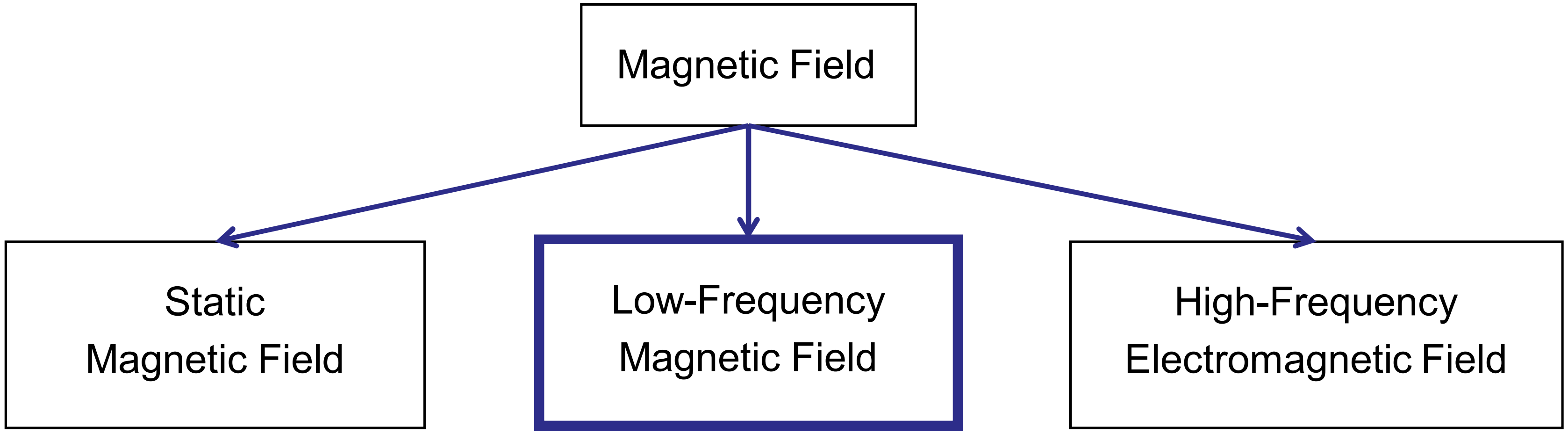


Institute of Technical Problems of Magnetism
of the National Academy of Sciences of Ukraine

Basic directions of scientific activity:

1. theory of magnetism of technical objects;
2. definition of magnetic parameters of technical objects;
3. control by the magnetic field of technical objects;
4. reduction of electromagnetic influence of objects of power engineering on a man and environment.

Classifications

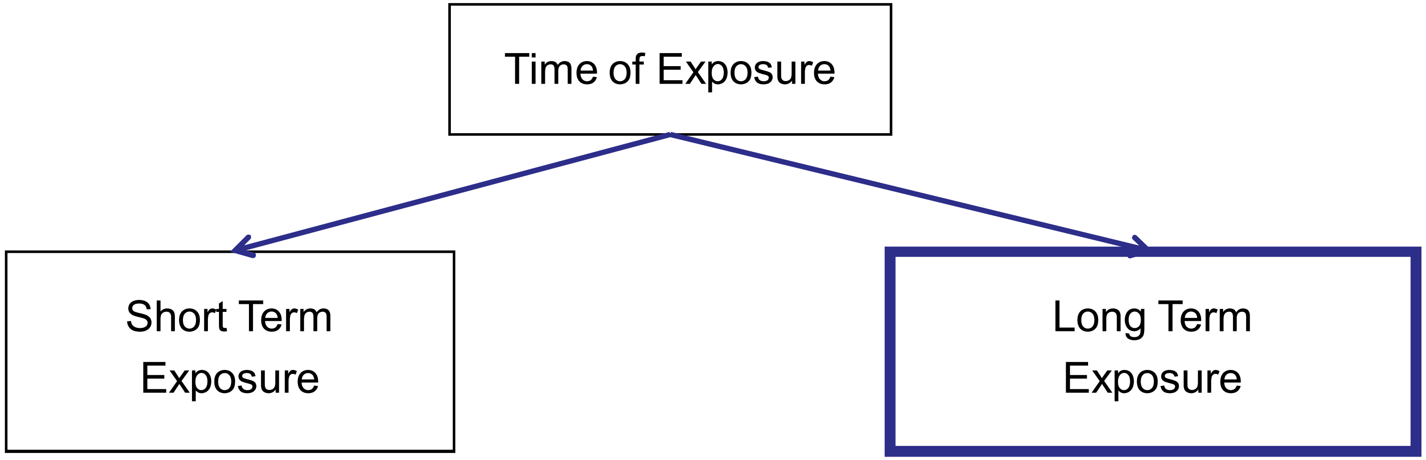


Different Biological Effects on Human

Different Physical Principle of Shielding

Different Standards and Limits

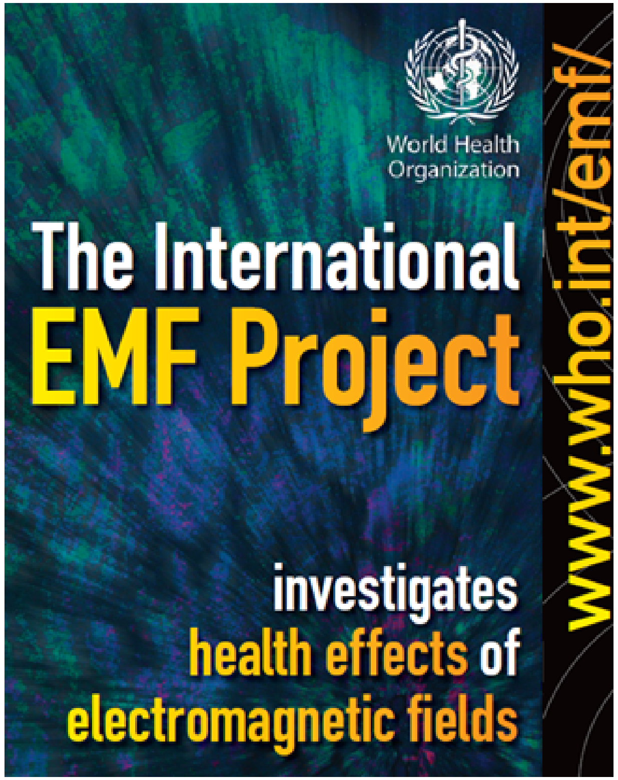
Different Shields / Shielding Systems



Effects of long-term exposure of power frequency magnetic field

1. Cells may encounter **replication problems**
   [F. Focke, et al., "DNA fragmentation in human fibroblasts under extremely low frequency electromagnetic field exposure," *Mutation Research*, vol. 683, pp. 74-83, 2009].
2. Changes in the hematological parameters of the blood and the **immune status**
   [L. Bonhomme-Faivre, et al., "Alterations of biological parameters of mice under chronic exposure to environmental low frequency (50 Hz) electromagnetic fields produced by transformer station," *Life Sciences*, no. 14, pp. 1271-1280, 1998].
3. Acts on the human **nervous system**
   [Marino A.A., et al., "Effect of low-frequency magnetic fields on brain electrical activity in human subjects," *Clinical Neurophysiology*, vol. 115, pp. 1195-1201, 2004].
4. Dysfunction of human **reproductive system**
   [Давыдов Б.И., Карпов В.П., "Постоянные электрические и электромагнитные поля низких частот (биологическое действие, гигиеническая оценка)," *Космическая биология и авиакосмическая медицина*, № 5, С. 18-23, 1982],
   [Davydov B.I. and Karpov V.P., "Static electric and low-frequency electromagnetic fields (biological effect, hygienic assessment)," *Cosmic Biology and Aerospace Me*, no. 5, pp. 18-23, 1982].
5. Acts on **central** and **neurovascular systems**
   [Загорская Е.А. и др., "Влияние низкочастотных электромагнитных полей на отдельные функциональные системы организма," Космическая биология и авиакосмическая медицина, № 3, С. 3-9, 1990],
   [Zagorskaya E.A. et al., "The effect of low-frequency electromagnetic fields on separate functional systems of the body," *Cosmic Biology and Aerospace Me*dicine, no. 3, pp. 3-9, 1990].

The International EMF Project
(by World Health Organization)



Existence of standards, Legislative status, and Exposure limits are available on-line at *http://apps.who.int/gho/data/node.main.EMF*

European Region

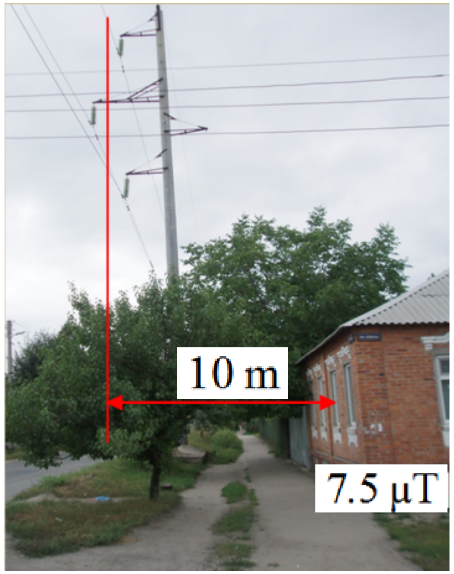
- Armenia
- Austria
- Belgium
- Bulgaria
- Croatia
- Cyprus
- Czech Republic
- Denmark
- Finland
- France
- Germany
- Greece
- Hungary
- Iceland
- Ireland
- Israel
- Italy
- Netherlands
- Norway
- Poland
- Portugal
- Russian Federation
- Slovenia
- Spain
- Sweden
- Switzerland
- Turkey
- United Kingdom

Exposure limits for low-frequency fields (public)

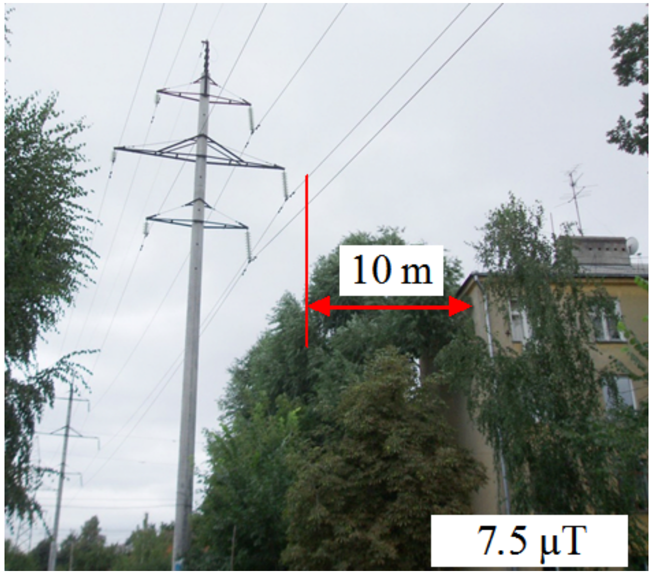
Country	Year	Electric field (kV/m) i	Magnetic flux density (microT) i
Argentina	2017	3 i	25
Belgium	2017	i	[0.4]/[100] i
Brazil	2017	4.17	83
Croatia	2018	2/5 i	40/100 i
Finland	2017	[5]/[15] i	[0.4]/[100]/[500] i
France	2017	5	[1]/100 i
Israel	2017	[5]	[0.4]/[100] i
Italy	2017	5	3/10/100 i
Netherlands	2017	[5]	[0.4]/[200] i
New Zealand	2017	5	100/[200] i
Norway	2017	5	[0.4]/200 i
Russian Federation	2017	0.5	5
Sweden	2017	[2.5]	[100]
Switzerland	2017	5	1/100 i

* http://apps.who.int/gho/data/node.main.EMFLIMITSPUBLICLOW?lang=en

High-voltage overhead line magnetic field



Kharkiv, Koltsovskaya st.



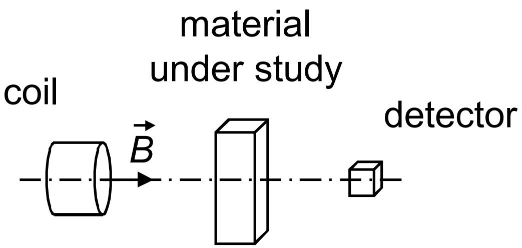
Kharkiv, Metalista st.

The reference levels of power frequency electric and magnetic field: *

electric field strength – 0.5 kV/m

magnetic flux density – **0.5 μT**

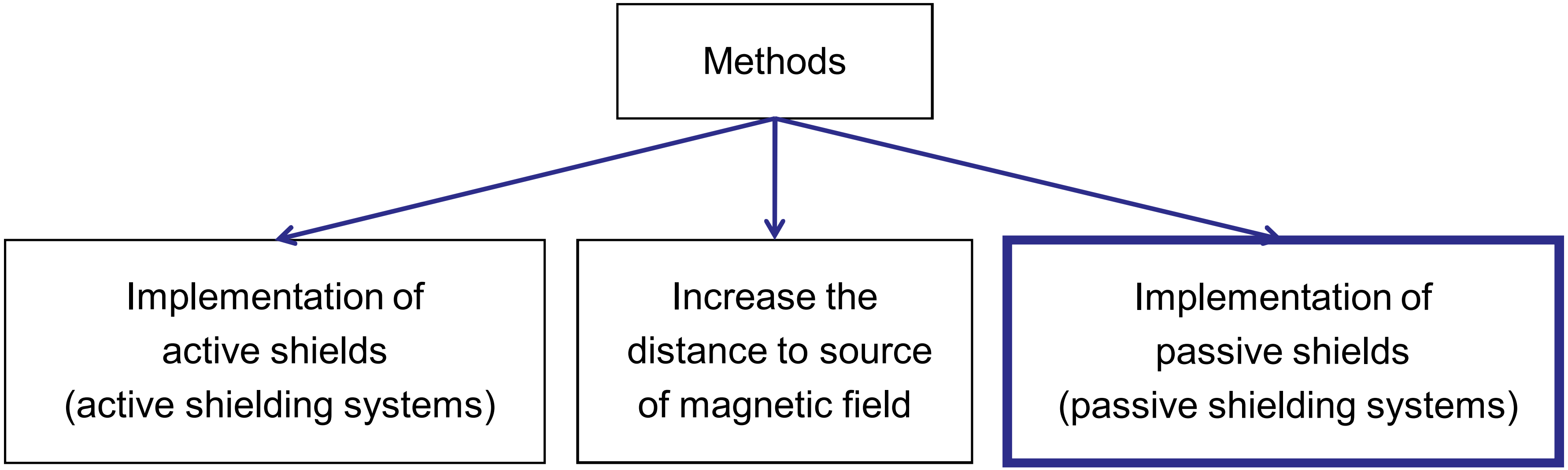
* *Electrical installation regulations*. Kyiv, Ukraine: The Ministry of Energy and Coal Mining of Ukraine, 2017.



Building Material	*Shielding Efficiency* *
White silicate brick	≈ 1
Red brick	≈ 1
Concrete	≈ (1÷1.02)
Reinforced Concrete	≈ (1÷1.02)

* D.Ye. Pelevin, “Screening magnetic fields of the power frequency by the walls of houses,” *Electrical engineering & Electromechanics*, no. 4, pp. 53-55, 2015.

Methods of magnetic field reduction



Active shield requires a source of electrical energy (to generate the current in its conductors), detectors and control system.

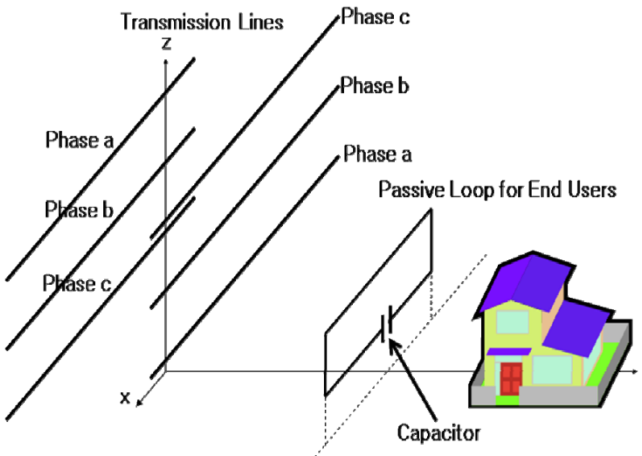
- \+ Comparably high shielding efficiency
- \+ Low metal intensity
- – Consume electrical energy
- – Expenses for maintenance checkup

Passive shield is made of conductive elements (plates, wires, etc.). Eddy currents inside are generated according to Faraday's Law.

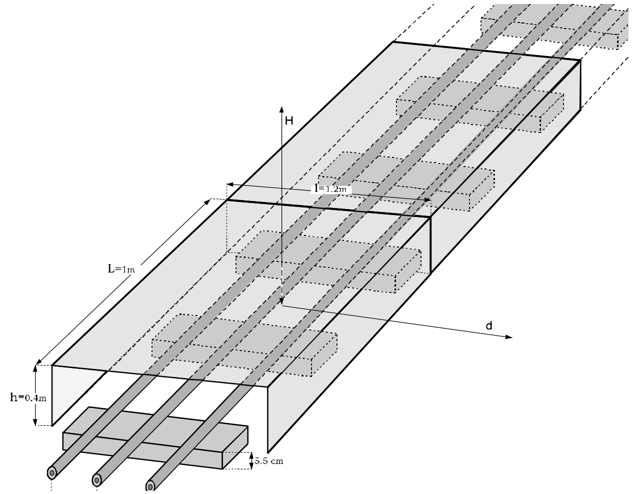
- \+ No maintenance checkup
- \+ Easier installation
- – Comparably high metal intensity

Types of passive shields for magnetic field reduction

“shielding of **source**”



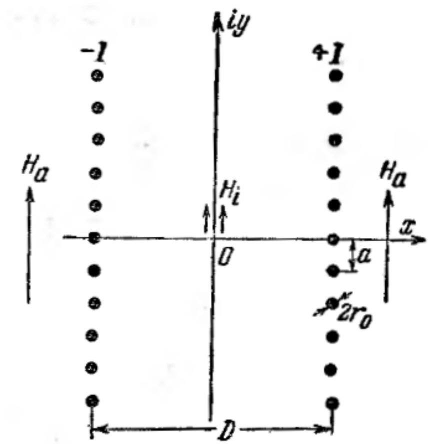
DOI: 10.5370/JEET.2011.6.6.829



J. Hoeffelman, “Shielding of underground power cables”, CIRED, 2003

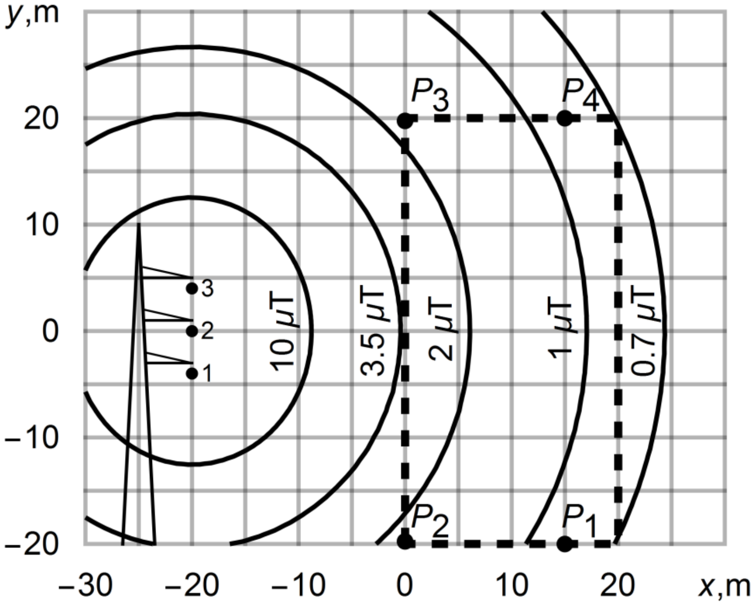
“shielding of **subject**”

Field Management Services comp.



H. Kaden, “Wirbelströme und Schirmung in der Nachrichtentechnik”, 1959, pp. 272-282

Parameters of overhead line, shielding area, and grid shield



Points 1, 2, 3 indicate the conductors of OHL.

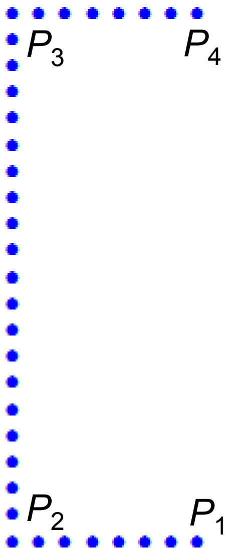
The area of interest is marked with dashed lines.

Points P_1 .. P_4 indicate the segments of shields.

$x_1=x_2=x_3=-20$ m,

$y_1=-4$ м, $y_2=0$, $y_3=4$ m

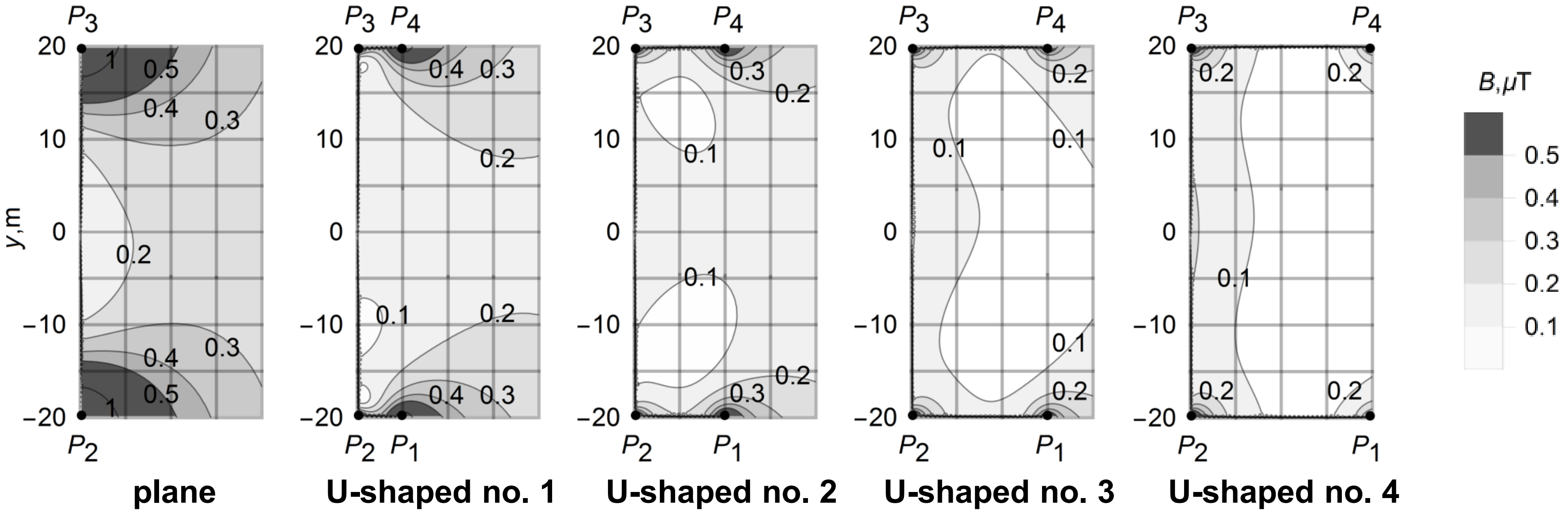
$I=1000$ A, $\varphi_1=-2\pi/3$, $\varphi_2=0$, $\varphi_3=2\pi/3$



Cross-Section of Grid Shield

	length of arms	number of wires *	radius of wire cross-section
plane grid shield	–	81	8.9 mm
U-shaped grid shield no. **1**	5 m	81+20	5.6 mm
U-shaped grid shield no. **2**	10 m	81+40	5.2 mm
U-shaped grid shield no. **3**	15 m	81+60	4.8 mm
U-shaped grid shield no. **4**	20 m	81+80	4.5 mm

* The distance between adjacent wires is equal to 0.5 m



The shielded magnetic field *B* (in μT) of the overhead line is shown with isolines. Each grey shaded region is limited by two isolines. The magnetic field varies from lower isoline value to higher one within corresponding region.

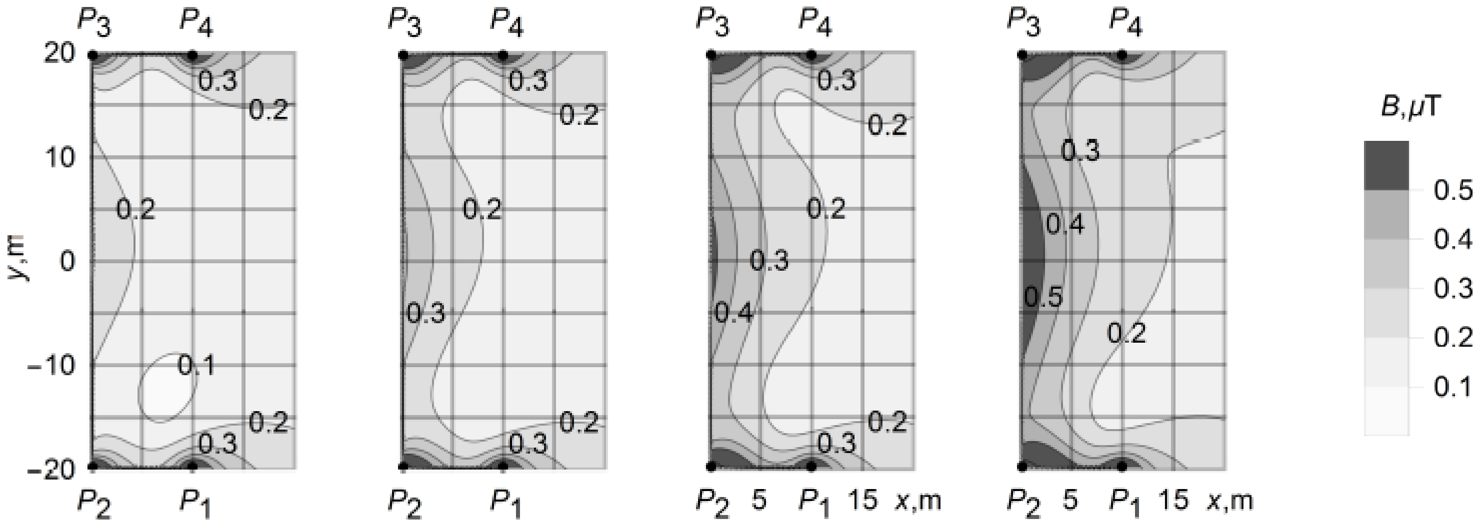
The **plane** grid shield is located in the vertical plane *x*=0. It provides low shielding efficiency on its **edges**.

The **U-shaped** grid shield **no. 2** reduces the magnetic field to **0.1–0.3 μT** in the most part of the shielding area. Thus the magnetic field level is below the reference level **0.5 μT**.

Decreasing of quantity of metal

We exchange wires with smaller cross-section ones in the U-shaped grid shield no. 2.

The quantity of metal is reduced **(a)** two times , **(b)** three times, **(c)** four times, and **(d)** five times.



(a) **(b)** **(c)** **(d)**

In Fig. (a)-(c) the grid shields reduce the magnetic field to 0.3–0.5 μT.

In Fig. (c) the subareas are 15 m^2 where *B* exceeds the reference level 0.5 μT.

Fig. (d) shows that the future decreasing of the quantity of metal is undesirable.

* V. Grinchenko and U. Pyrohova, "Mitigation of overhead line magnetic field by U-shaped grid shield," in *Proc. 2019 IEEE 2nd Ukraine Conf. Electrical and Computer Engineering*, pp. 345-348.

Maxwell equations and quasi-stationary approximation

$$\begin{cases} \nabla \times \mathbf{H} = \boldsymbol{\delta}_{ext} + \sigma\,\mathbf{E} + \dfrac{\partial \mathbf{D}}{\partial t} \\ \nabla \times \mathbf{E} = -\dfrac{\partial \mathbf{B}}{\partial t} \\ \nabla \cdot \mathbf{B} = 0 \\ \nabla \cdot \mathbf{D} = \rho \end{cases}$$

$\sigma\mathbf{E}$ – conduction current

$\boldsymbol{\delta}_{ext}$ – density of currents, created by extenal sources

ρ – charge density

ω, λ – frequency and wave length

L – characteristic size of the system

$$\mathbf{B} = \mu\,\mu_0\mathbf{H}$$

$$\mathbf{D} = \varepsilon\,\varepsilon_0\mathbf{E}$$

μ – relative permeability

ε – relative permittivity

The conditions of quasi-stationary approximation are the following:

$$\begin{cases} L << \lambda \\ \omega\,\varepsilon\,\varepsilon_0 << \sigma \end{cases} \Leftrightarrow \begin{cases} f << \dfrac{c}{2\pi\,L} \\ f << \dfrac{\sigma}{2\pi\,\varepsilon\,\varepsilon_0} \end{cases}$$

$$c = 3 \cdot 10^8\ \frac{\mathrm{m}}{\mathrm{s}}$$

$$\varepsilon_0 = 8.85 \cdot 10^{-12}\ \frac{\mathrm{F}}{\mathrm{m}}$$

Maxwell equations and quasi-stationary approximation

$$\begin{cases} \nabla \times \mathbf{H} = \boldsymbol{\delta}_{ext} + \sigma\,\mathbf{E} + \cancel{\dfrac{\partial \mathbf{D}}{\partial t}} \\ \nabla \times \mathbf{E} = -\cancel{\dfrac{\partial \mathbf{B}}{\partial t}}\ \ 0 \\ \nabla \cdot \mathbf{B} = 0 \\ \nabla \cdot \mathbf{D} = \rho \end{cases}$$

$\sigma\,\mathbf{E}$ – conduction current

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ω, λ – frequency and wave length

L – characteristic size of the system

$$\mathbf{B} = \mu\,\mu_0 \mathbf{H}$$

$$\mathbf{D} = \varepsilon\,\varepsilon_0 \mathbf{E}$$

μ – relative permeability

ε – relative permittivity

Since the conditions of quasi-stationary approximation are satisfied, then the system of Maxwell equations splits into two systems.

$$\begin{cases} L << \lambda \\ \omega\,\varepsilon\,\varepsilon_0 << \sigma \end{cases} \Leftrightarrow \begin{cases} f << \dfrac{c}{2\pi\,L} \\ f << \dfrac{\sigma}{2\pi\,\varepsilon\,\varepsilon_0} \end{cases} \Rightarrow \begin{cases} \nabla \times \mathbf{H} = \boldsymbol{\delta}_{ext} + \sigma\,\mathbf{E} \\ \nabla \cdot \mathbf{H} = 0 \end{cases} \quad \begin{cases} \nabla \times \mathbf{E} = 0 \\ \nabla \cdot \mathbf{E} = \dfrac{\rho}{\varepsilon\,\varepsilon_0} \end{cases}$$

$$\begin{cases} \mathbf{B} = \nabla \times \mathbf{A} \\ \mathbf{E} = -\nabla \varphi - \dfrac{\partial \mathbf{A}}{\partial t} \end{cases}$$

$\mathbf{A}$ – the magnetic vector potential

φ – the electric potential

$\mathbf{B}, \mathbf{E}, \mathbf{A}, \varphi \sim \exp(j\omega t)$, $j = \sqrt{-1}$ **=>** $\mathbf{A} = \dot{\mathbf{A}} \cdot \exp(j\omega t)$

$\dot{\mathbf{A}} = \{0, 0, \dot{A}(x, y)\}$

$\partial/\partial z$ for $2D$ problem

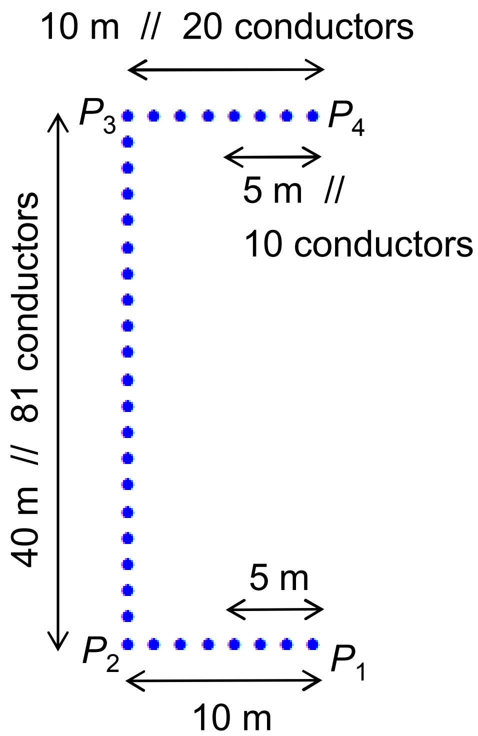
=>

$$\begin{cases} \dfrac{\partial^2 \dot{A}_i}{\partial x^2} + \dfrac{\partial^2 \dot{A}_i}{\partial y^2} - j\mu_0 \omega \sigma \dot{A}_i = -\mu_0 \dot{\delta}_{ext}, \text{ if } \sigma \neq 0, \\ \dfrac{\partial^2 \dot{A}_e}{\partial x^2} + \dfrac{\partial^2 \dot{A}_e}{\partial y^2} = 0, \text{ if } \sigma = 0, \end{cases}$$

$$\begin{cases} \dot{A}_i = \dot{A}_e, \\ \dfrac{\partial \dot{A}_i}{\partial n} = \dfrac{\partial \dot{A}_e}{\partial n}. \end{cases}$$

are the boundary conditions between conductive domains and non-conductive external environment

Optimization algorithm



Cross-Section of Grid Shield

The location of conductors is fixed.

The distance between adjacent conductors is 0.5 m.

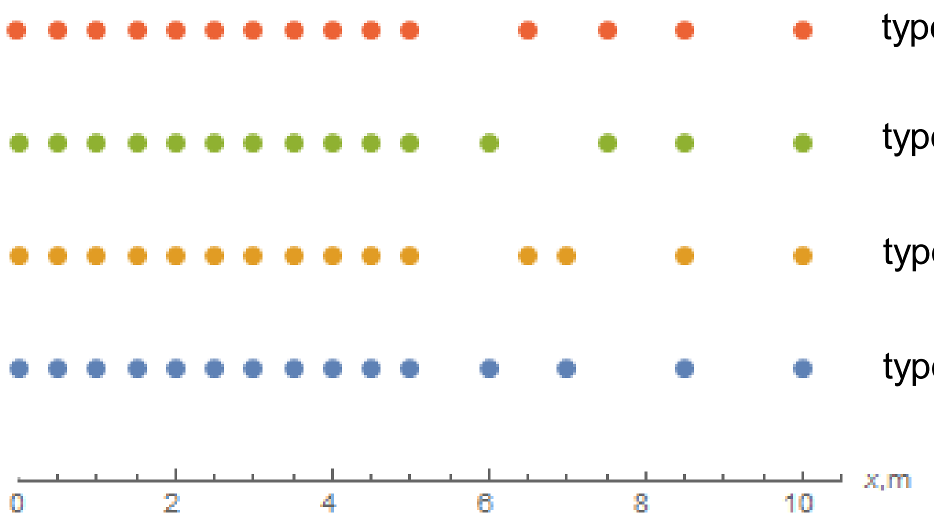
The radius of most part of conductors is r_0=4 mm.

The radius of 10 “edge conductors” on each arm is varied: 0 , $r_0/2$, and r_0.

The total number of variants of grid shield geometry for enumeration is 3^10 ≈ 59 000.

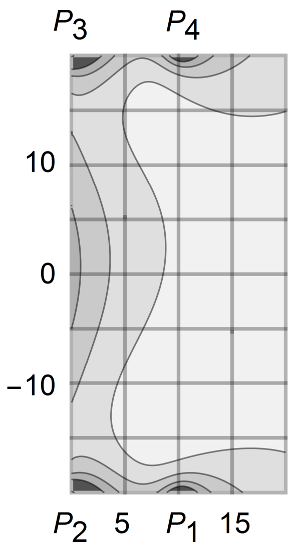
Application of criteria B<0.5 μT for test points:	366 variants left.
Application of criteria of minimum total cross-section:	105 variants left.
Shield does not contain half-radius conductors:	4 variants left.

Results of optimization

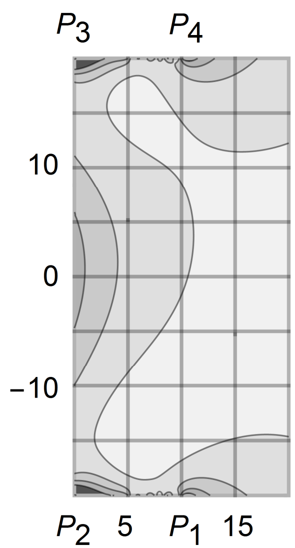


Arrangement of conductors in arms of grid shield

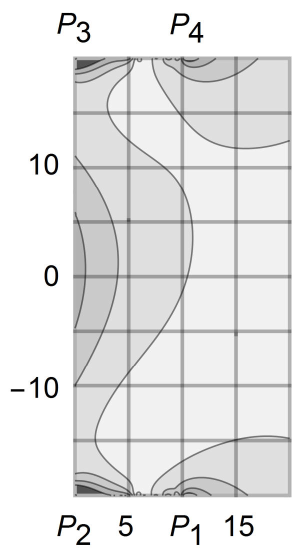
The usage of these types of arms allow to reduce the metal intensity of the grid shield by **10%**.



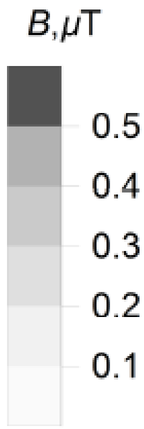
U-shaped grid shield with “full” arm



U-shaped grid shield with arm no. 1

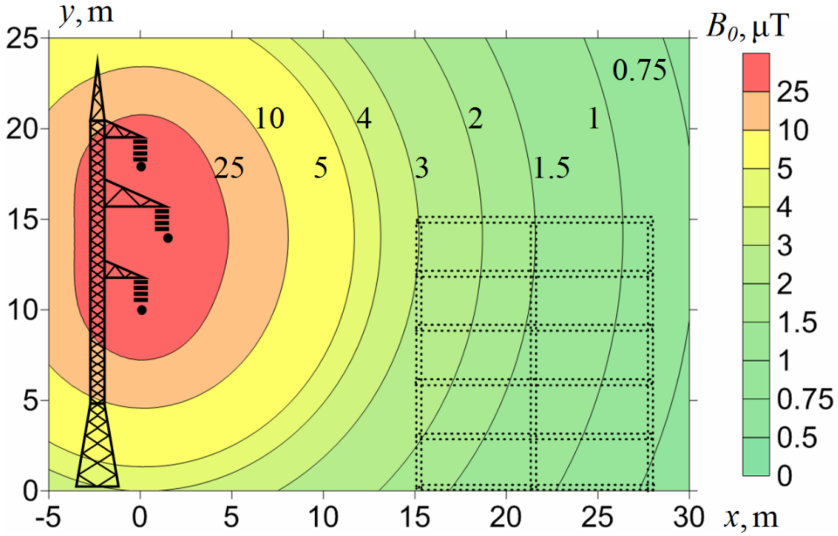


U-shaped grid shield with arm no. 4

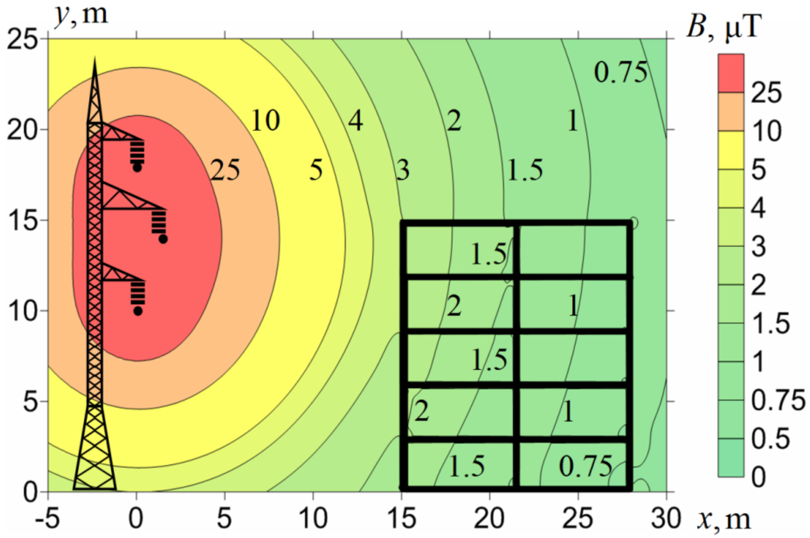


Thank you for attention.

FAQ 1. *Results of the magnetic field simulation*



The overhead line magnetic field
in the absence of the building (μ=1)



$\mu = \mu_{eff} = 3{,}5$

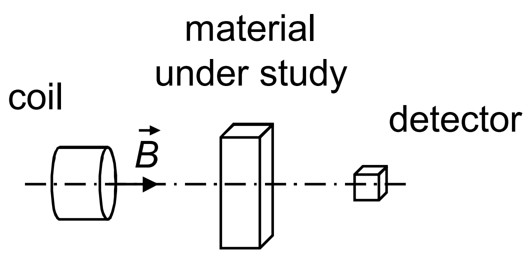
Table 1. The RMS value of the magnetic flux density

room	observation point	B_0, μT	B, μT $\mu_{эфф}$ = 3,5	S_B	room	observation point	B_0, μT	B, μT $\mu_{эфф}$ = 3,5	S_B
1 floor/left side	x=18 m, y=1 m	1,47	1,41	1,04	1 floor/right	x=24,5 m, y=1 m	0,94	0,92	1,02
2 floor/left side	x=18 m, y=4 m	1,70	1,60	1,06	2 floor/right	x=24,5 m, y=4 m	1,03	0,97	1,06
3 floor/left side	x=18 m, y=7 m	1,91	1,77	1,08	3 floor/right	x=24,5 m, y=7 m	1,10	1,03	1,08
4 floor/left side	x=18 m, y=10 m	2,09	1,91	1,09	4 floor/right	x=24,5 m, y=10 m	1,12	1,06	1,09
5 floor/left side	x=18 m, y=13 m	2,17	1,98	1,10	5 floor/right	x=24,5 m, y=13 m	1,19	1,09	1,09

The magnetic field shielding factor S_B is more than 1.02 и less than 1.10.

* V. Rozov and V. Grinchenko, "Simulation and analysis of power frequency electromagnetic field in buildings closed to overhead lines," in *Proc. 2017 IEEE 1st Ukraine Conf. Electrical and Computer Engineering*, pp. 500-503.

FAQ 2. *The experiment results*

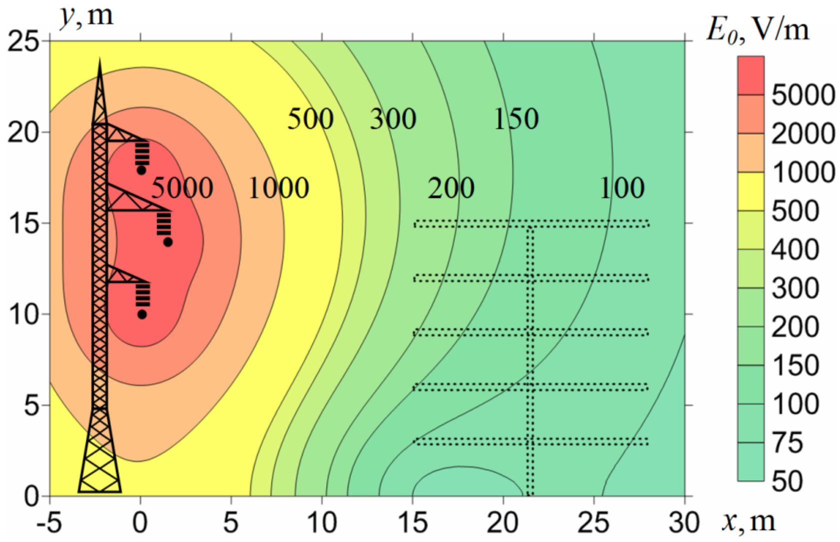


Material under study	Shielding factor
White silicate brick	≈ 1
Red brick	≈ 1
Concrete	≈ (1÷1.02)
Reinforced Concrete	≈ (1÷1.02)

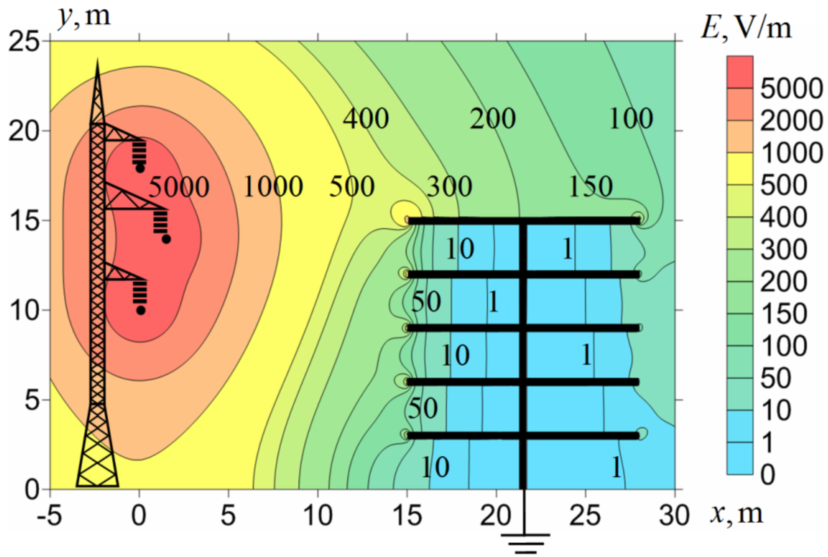
Type of the building	Shielding factor
9-floor building	≈ 1.03
16-floor building	≈ 1.04
9-floor building	≈ (1÷1.03)
5-floor building	≈ (1÷1.02)

* D.Ye. Pelevin, "Screening magnetic fields of the power frequency by the walls of houses," *Electrical engineering & Electromechanics*, no. 4, pp. 53-55, 2015.

FAQ 3. *Results of the electric field simulation*



Overhead line electric field distribution



Electric field distribution in the building

Table 2. The RMS value of the electric field strength

room	observation point	E_0, V/m	E, V/m	S_E	room	observation point	E_0, V/m	E, V/m	S_E
1 floor/left side	x=18 m, y=1 m	72,3	1,65	43,8	1 floor/right	x=24,5 m, y=1 m	76,0	0,06	≥100
2 floor/left side	x=18 m, y=4 m	93,7	4,00	23,4	2 floor/right	x=24,5 m, y=4 m	80,5	0,18	
3 floor/left side	x=18 m, y=7 m	125	5,17	24,4	3 floor/right	x=24,5 m, y=7 m	88,7	0,33	
4 floor/left side	x=18 m, y=10 m	157	5,51	28,5	4 floor/right	x=24,5 m, y=10 m	97,7	0,57	
5 floor/left side	x=18 m, y=13 m	179	8,42	21,3	5 floor/right	x=24,5 m, y=13 m	105	1,11	

The electric field shielding factor S_E is more than 20.

* V. Rozov and V. Grinchenko, “Simulation and analysis of power frequency electromagnetic field in buildings closed to overhead lines,” in *Proc. 2017 IEEE 1st Ukraine Conf. Electrical and Computer Engineering*, pp. 500-503.