Marek PAVLÍK[1]

Technical university of Kosice (1)

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Compare of shielding effectiveness for building materials

***Abstract**. During the 1990s, most electromagnetic field research focused on extremely low frequency exposures stemming from conventional power sources, such as power lines, electrical substations, or home appliances. Now, in the age of mobile telephones, wireless routers, and portable GPS devices (all known sources of EMF radiation), concerns regarding a possible connection between EMFs and adverse health effects still persist. This paper deals with compare the shielding effectiveness of various building materials. Measurements were performed into non-reflection chamber for frequency - 1,5 GHz 2 GHz, 2,5 GHz, 3 GHz and 3,5 GHz. Measurements were performed according to the IEEE Standard, Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures. Measurements were performed in the non-reflection chamber in order to avoid the exterior influence.*

***Streszczenie.** Niniejszy artykuł dotyczy porównania skuteczności ekranowania różnych materiałów budowlanych. Pomiary przeprowadzono w komorze bezodbicia dla częstotliwości - 1,5 GHz 2 GHz, 2,5 GHz, 3 GHz i 3,5 GHz. Pomiary przeprowadzono zgodnie ze Standardem IEEE, Metodą Pomiaru Skuteczności Obudów Ekranów Elektromagnetycznych. Pomiary przeprowadzono w komorze bezodbiciowej, aby uniknąć wpływu zewnętrznego. (**Porównanie skuteczności ekranowania materiałów budowlanych**).*

Keywords: electromagnetic field, shielding effectiveness, building materials.
Słowa kluczowe: pole elektromagnetyczne, skuteczność ekranowania, materiały budowlane.

Introduction

With the exponential growth of wireless technologies nowadays, there is an increase in the presence and use of number of mobile communications, excessive installation of mobile phone antenna masts, and broadcasting radio and TV transmitters, and even satellite systems. The mobile phone shielding device was primarily used in some special department (e.g. the army or the security). However, in recent years, the mobile phone shielding device has been widely used in the meeting room, examination room, library, cinema, hospital, court and church. Radio frequency used in mobile communication has the ability to penetrate through semi-solid substances like meat and living tissue. The researchers conducted shows that the electromagnetic wave produce by the mobile phone might cause adverse effect to human especially at place near the ear region. Table I below illustrates some typical artificial sources of electromagnetic fields with frequency and intensity. Natural sources like the magnetic field of the earth are not included [1, 2, 3].

The effects of electromagnetic field on organism have been the issue concerned by environmental, electrical, biological, medical and related subjects. From the perspective of the dielectric properties of organisms, the pulsed electromagnetic field may cause a stronger influence on organism. So since the last century, the academic and clinical medicine have shown an interest in biological effects of pulsed electromagnetic fields on organism, with the deepening of the research, many valuable results have been acquired: researches not only have established the model of cell membrane potential, but also have found the theoretical basis for the clinical application of magnetic field to treat cancer [2, 3, 4, 15, 16].

Everyone is affected by electromagnetic radiation and radio frequency radiation from all appliances, cell phones, wifi devices, cordless phones, computers, laptops, and television waves. Electromagnetic field causes invisible threats to our health. Prolonged exposure to electromagnetic radiation causes physiological change in human. It is therefore important to focus on the protection of human against exposure of electromagnetic radiation. People work and live in buildings that constitute the shielding against electromagnetic fields. The electromagnetic field penetrates through the wall of the building from the outside. Therefore, the experiment was focused on the building materials [3, 4].

The number of studies focused on the impact of mobile devices and Wireless sources to human health. However, problem is that also in the current studies, long-term mobile phone and Wireless internet users have had hardly more than 10 years of regular use of mobile phones. It still may be a relatively short latency period, particularly for slowly growing benign tumours. Among those long-term users, most were initially users of analogue mobile phone and thus, the number of long-term users of the digital technology is even smaller [5, 6].

Table 1. The sources of electromagnetic field

Frequency range	Frequencies [Hz]	Some examples of exposure sources
Static	0	VDU (video displays); MRI and other diagnostic / scientific instrumentation; Industrial electrolysis
ELF	0-300 Hz	Powerlines; Domestic distribution lines, Domestic appliances
IF	300 Hz – 10^5 Hz	VDU; anti theft devices in shops, hands free access control systems, card readers and metal detectors
RF	100 kHz – 300 GHz	Mobile telephony; Broadcasting and TV; Microwave oven; Radar, portable and stationary radio

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Shielding effectiveness

Quality shielding materials are determined by three coefficients, shielding coefficient KS, absorption coefficient A and a reflection coefficient R. The shielding effectiveness SE is closely related with coefficient KS, R, and A. Shielding coefficient KS is determined by the intensity of electric field strength E, possibly based on the intensity of the magnetic field H by the relation [4]:

(1) $K_S = \frac{E_2}{E_1}; K_S = \frac{H_2}{H_1}$ [-]

where E_2 is intensity of electric field measured using the antenna placed in the prescribed configuration within the enclosure, E_1 is intensity of electric field measured using the antenna placed in the prescribed configuration in the absence of the enclosure, H_2 is intensity of magnetic field measured using the antenna placed in the prescribed configuration within the enclosure, H_1 is intensity of magnetic field measured using the antenna placed in the prescribed configuration in the absence of the enclosure.
Shielding effectiveness *SE* is calculated using the formula (2-4) if intensity of electric field and intensity of magnetic field are in basic units [4, 5, 6].

(2) $SE = 20\log\frac{1}{|K_S|} = 20\log\frac{|H_1|}{|H_2|} = 20\log\frac{|E_1|}{|E_2|}$ [dB]

Formula varies for determining of the shielding effectiveness *SE* according to the frequency range. According to [7], the shielding effectiveness is determined by the relation:

(3) $SE = 20\log\frac{|H_1|}{|H_2|} = 20\log\frac{|V_1|}{|V_2|}$ [dB]

For the frequency range from 50 Hz to 20 MHz and for the frequency range from 20 MHz to 300 MHz and also the same applies to the frequency range 300 MHz to 100 GHz [7]:

(4) $SE = 20\log\frac{|E_1|}{|E_2|} = 10\log\frac{P_1}{P_2}$ [dB]

where E_1 and H_1 are the intensity of electric field and magnetic field at any point in the space where there are no shielding materials respectively. E_2 and H_2 are the intensity of electric field and magnetic field where the shielding materials are in the same place. V_2 is voltage reading within the enclosure, V_1 is voltage reading in the absence of the enclosure and P_2 is power detected within the enclosure, P_1 is power detected in absence of the enclosure. Then *SE* of the material was calculated at specific frequency by using (4) [7, 10, 11].
The main factors which determine the shielding effect are the capability of shielding materials (the electric and magnetic conductivity and the permeability), the thickness and the frequency of the incident wave. If we know all these factors, the materials shielding effects can be calculated by (5). If these factors are unknown, we can measure the intensity of electric field and magnetic field when there are shielding materials or not, and then SE could be calculated by (2). According to [8] shielding effectiveness is the sum of the reflection *R*, multiple reflection *B* and absorption *A* of electromagnetic field derived as [8, 9]:

(5) $SE = A + R + B$

$$SE = 15{,}4t\sqrt{f\mu\sigma} + 168{,}16 - 10\log\frac{\mu_R f}{\sigma_R} + 20\log\left(1 - e^{\frac{2t}{\delta}}\right)$$

where *t* is material thickness, *σ* is electrical conductivity of shielding material, σ_R is the relative conductivity, μ_R is the relative permeability of shielding material, *μ* is the magnetic permeability of shielding material, *f* is frequency, *δ* is depth of penetration. For the simplicity, it is possible to determine the shielding effectiveness *SE* also as (6) without the multiple reflections *B* [8, 10].

(6) $SE = A + R$

Shielding effectiveness can be calculated according to the relations (7-10) if the value of the transmitted signal is set in logarithmic unit [7, 20, 23].

Formula (7), (8), (9), (10) is used according to the available measuring equipment [8, 9, 10, 24].

(7) $SE = |E_{1\log}| - |E_{2\log}|$ [dB]

(8) $SE = |H_{1\log}| - |H_{2\log}|$ [dB]

(9) $SE = |V_{1\log}| - |V_{2\log}|$ [dB]

(10) $SE = P_{1\log} - P_{2\log}$ [dB]

Experiment

The experiment was focused on measuring of shielding effectiveness of electromagnetic field. Measured objects were bricks the air gaps constitute 60% of Sample 1 and the air gaps constitute 80% of Sample 2. Measurements were performed in the non-reflection chamber because exterior influence. The workplace for purpose of measuring of shielding effectiveness of electromagnetic field is shown on Fig. 1 - block scheme of the workplace.

This workplace consists of an analog signal generator Agilent N5181A, EMI receiver Agilent N9038A MXE EMI, the receiving antenna and transmitting antenna horn type. Antennas were placed indoor of non-reflection chamber. Analog signal generator and spectrum analyzer were placed outdoor of non-reflection chamber. The workplace calibration was performed before the measurement. Measured object was placed at a distance of 0.3 m from the transmitting antenna [14, 15, 18, 25].

The workplace calibration was performed before the measurement. The calibration of measuring workplace was based on radio communication equation (11), which is defined as follows: [6, 12, 13, 14, 17, 18, 19]

(11) $P_R = P_T - L_0 + G_T + G_R$

where P_R is received power, P_T is transmit power, L_0 is loss of free space, G_T is gain of transmitting antenna and G_R is gain of receiving antenna. The loss of free space is defined as follows: [6, 12, 20. 21, 22]

(12) $L_0 = 20\log\frac{4\pi R}{\lambda}$

Where *R* is distance of antennas and *λ* is wavelength. The calibration was performed at a frequency of 1 GHz without shielding.

The measurements were performed in two steps – with shielding and without shielding. Subsequently. And therefore, shielding effectiveness was calculated by the formula (10).

The measured objects were brick wall, polystyrene (thickness 25 mm and 50 mm), eco-material (Natura Pro with thickness 8 mm and Eterplan with thickness 8 mm) – Fig. 2.

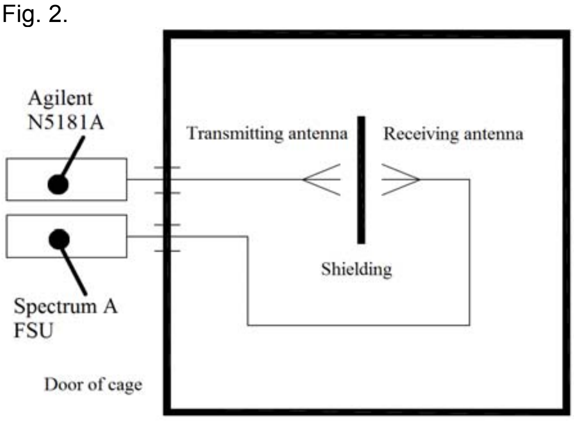

Fig.1. Workplace for purpose of measuring shielding effectiveness of electromagnetic field - block scheme

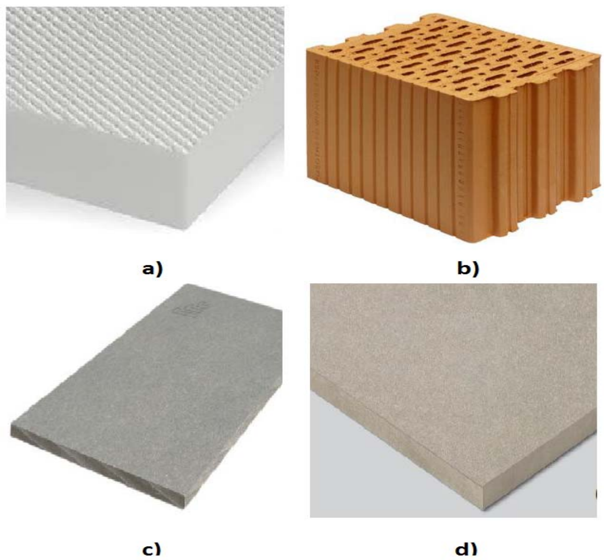

Fig.2. Measured objects – a) polystyrene b) brick c) eco material Natura Pro d) eco material Eterplan

Results

The measurements were performed for frequency 1.5 GHz, 1.8 GHz, 2.1 GHz, 2.2 GHz, 2.3 GHz, 2.4 GHz, 2.6 GHz, 2.7 GHz, 3.4 GHz and 3.5 GHz. They are currently the most used frequency and also they are frequencies which are planned to be used in the future.

The Fig. 4 represents a dependence of the shielding effectiveness of electromagnetic field for polystyrene (25 mm and 50 mm), bricks wall, eco-materials Eterplan and Natura Pro. The results show that the lowest value of shielding effectiveness has polystyrene with thickness 25 mm. The highest value of shielding effectiveness has brick. In the frequency range from 1.5 GHz to 3.5 GHz the shielding effectiveness has increasing trend for all building materials. The fastest rising trend has a brick. From among the eco materials the higher shielding effectiveness has eco material Natura Pro.

The Fig. 4 shown the shielding effectiveness of 25 mm polystyrene is lower like the shielding effectiveness of 50 mm polystyrene. Polystyrenes are the same type. It follows that the material thickness influences shielding effectiveness. This experiment confirmed expression (6).

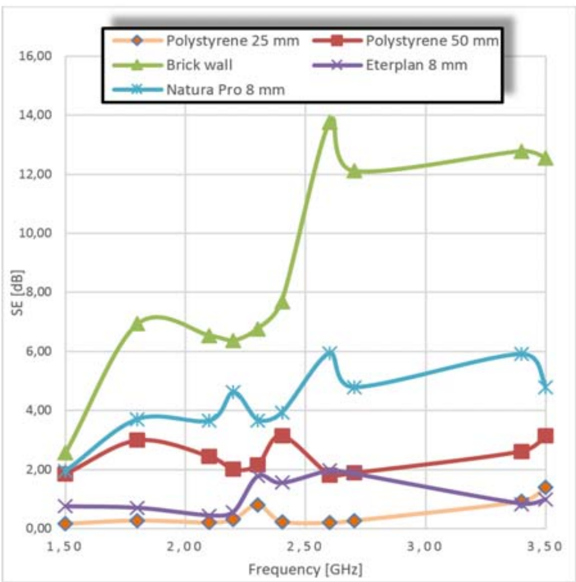

Fig.3. Shielding effectiveness for frequencies 1.5 GHz, 1.8 GHz, 2.1 GHz, 2.2 GHz and 2.3 GHz

Conclusion

The walls of buildings are a natural shielding against electromagnetic fields. This article was discussed measuring of shielding effectiveness for building materials - polystyrene with thickness 25 mm and 50 mm, brick wall, eco material Eterplan, eco material Natura Pro. The measurements were performed for frequency 1.5 GHz, 1.8 GHz, 2.1 GHz, 2.2 GHz, 2.3 GHz, 2.4 GHz, 2.6 GHz, 2.7 GHz, 3.4 GHz and 3.5 GHz. These are the current used frequency or frequencies, which are planned for the future. The Measuring of electromagnetic field shielding was performed according IEEE 299-2006 Standard, Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures. Shielding was placed in the non-reflection chamber because exterior influence.

This article compares the shielding effectiveness of building materials. From the results it is clear the shielding effectiveness of brick wall is the best among all the shielding material. It is necessary to realize that uncertainty of measurement occurs during this measurement. The overall uncertainty of measurement equals 0,35 dB. Calculation of uncertainty was done based on the document of Slovak national accreditation service which defines the following sources impacting uncertainty of measurement:

- Relative amplitude accuracy of spectral analyzer
- Amplitude stability of source of signal
- Errors occurring during transmitting
- Errors occurring during receiving

With an increasing number of electromagnetic fields sources it is necessary to researched their shielding effectiveness of electromagnetic fields. Currently, there are the paint to the walls, which increase the shielding effectiveness.

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***Authors**: Ing. PhD., Marek Pavlík, Department of Electric Power Engineering, Faculty of Electrical Engineering and Informatics, Technical university of Kosice, E-mail: marek.pavlik@tuke.sk*

REFERENCES

[1] HAO, C., DENGHUA, L., Simplified Model of Shielding Effectiveness of a Cavity with Apertures on Different Sides, *IEEE Transactions on Electromagnetic Compatibility*, Vol.56, No.2, 2014, pp.615-621, ISSN: 0018-9375.

[2] CELOZZI, S., ARANEO, R., Alternative Definitions for the Time-Domain Shielding Effectiveness of Enclosures, *IEEE Transactions on Electromagnetic Compatibility*, Vol.56, No.2, pp.482-485, 2014, ISSN: 0018-9375.

[3] LIPTAI, P. et al., Impact analysis of the electromagnetic fields of transformer stations close to residential buildings, *SGEM 2014: 14th international multidiscilinary scientific geoconference* : GeoConference on Ecology, Economics, Education and Legislation : conference proceedings : pp. 17-26. june, 2014, Albena, Bulgaria. - Sofia : STEF92 Technology, pp. 355-360. - ISBN 978-619-7105-17-9.

[4] KRAWCZYK, A., MIASKOWSKI, A., The Influence of the Electromagnetic Wave Polarization on SAR in Human Body Model, *Przegląd Elektrotechniczny*, Vol. 2006, No. 05, pp. 61-62, ISSN 0033-2097.

[5] KOZIOROWSKA, A., KOZIOL, K., GNIADY, S. and ROMEROWICZ-MISIELAK, M., An electromagnetic field with a frequency of 50 Hz and a magnetic induction of 2.5 mT affects spermatogonia mouse cells (GC-1spg line), *Przegląd Elektrotechniczny*, Vol. 2018, No. 06, pp. 132-135, ISSN 0033-2097.
[6] HAO, C., DENGHUA, L., Simplified Model of Shielding Effectiveness of a Cavity with Apertures on Different Sides, *IEEE Transactions on Electromagnetic Compatibility*, Vol.56, No.2, 2014, s.615-621, ISSN: 0018-9375.
[7] PAVLÍK, M. et al., Measuring of Dependence of Shielding Effectiveness of Wet Materials on The Frequency of Electromagnetic Field in the High Frequency Range, *Acta Electrotechnica et Informatica*. Vol. 13, No. 3, 2013, pp. 12-16, ISSN 1335-8243.
[8] MEDVEĎ D., KANÁLIK M., Measurement of power quality on the COTEK S1500-124 Inverter's terminals in case of linear load supplying, In: Universal Journal of Electrical and Electronic Engineering, Vol. 2, no. 4 (2014), p. 178-182. - ISSN 2332-3280.
[9] IEEE 299-2006 Standard: Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures, EMC Society, New York 2006, p.39.
[10] LIPTAI, P., et al., Impact analysis of the electromagnetic fields of transformer stations close to residential buildings, *SGEM 2014*, 14th international multidiscilinary scientific geoconference, Vol. 1, Issue 5 (2014), Albena, Bulgaria. p. 355-360., ISSN 1314-2704.
[11] GUAMG, Y., Analysis of Electromagnetic Field on the Permeability Test of Concrete, *Power and Energy Engineering Conference (APPEEC)*, Asia-Pacific, Shanghai, 27-29 march, 2012, pp. 1-2, ISSN:2157-4839.
[12] LUMNITZER, E., LIPTAI, P., DRAHOŠ, R., Measurement and Assessment of Pulsed Magnetic Fields in the Working Environment, *Elektroenergetika 2015*, pp. 331-333. - ISBN 978-80-553-2187-5.
[13] TUMAŃSKI, S., Modern magnetic field sensors – a review, *Przegląd Elektrotechniczny*, Vol. 2013, No. 10, pp. 1-12, ISSN 0033-2097.
[14] TADEUSZ, W., JANUKIEWICZ, M., Methods for Evaluating the Shielding Effectiveness of Textiles, *Fibres and Textiles in Eastern Europe*, Vol.14, No.5, 2006, ISSN: 1230-3666.
[15] BAMBYNEK, D., JAKUBAS, A., JABLONSKI, P., Examination of the possibilities to shield the electromagnetic field by selected polymer composites, *Przegląd Elektrotechniczny*, Vol. 2017, No. 01, pp. 121-124, ISSN 0033-2097.
[16] KOVAČ, D., et al. "An Automated Measuring Laboratory (VMLab) in Education." International Journal Of Engineering Education 32.5 (2016): 2250-2259.
[17] DOLNÍK, B., Electromagnetic compatibility. (Elektromagnetická kompatibilita), Technical university of Kosice, 2013, monography. ISBN 978-80-8086-221-3.
[18] ZBOJOVSKÝ, J., LIPTAI, P., MORAVEC, M., Modelling and calculating the shielding effectiveness of building materials, *Technical sciences and technologies*. Vol. 6, no. 4 (2016), p. 205-210. - ISSN 2411-5363.
[19] KISIELEWICZ, T., et al., Lightning electromagnetic pulse (LEMP) influence on the electrical apparatus protection, Przegląd Elektrotechniczny, Vol. 2014, No. 01, pp. 1-4, ISSN 0033-2097.
[20] CIMBALA, R., GERMAN-SOBEK, M. and BUCKO, S., The Assessment of influence of thermal aging to dielectric properties of XLPE insulation using dielectric relaxation spectroscopy, Acta Electrotechnica et Informatica. Vol. 15, No. 3 (2015), s. 14-17. - ISSN 1335-8243.
[21] KOVÁČ, D., et al., Circuit elements influence on optimal number of phases of DCDC buck converter, In: Electronics Letters. Vol. 54, no. 7 (2018), p. 435-436. - ISSN 0013-5194.
[22] ČEŠKOVIČ, M., BUCKO, S., MIĽO, M., LABUN, J., Antennas for UAV application, In: Aeronautika 17. - Lublin : University College of Enterprise and Administration, 2017 P. 230-237. - ISBN 978-83-60617-49-6
[23] TOMČÍKOVÁ, I., BEREŠ, M., KOVÁČOVÁ, I. and MELNYKOV, V., Interaction between magnetic and stress field in ferromagnetic core of magnetoelastic pressure force sensor, International Conference on Modern Electrical and Energy Systems (MEES), Kremenchuk, 2017, pp. 124-127. doi: 10.1109/MEES.2017.8248868
[24] ŠPES, M. et al., Impact of enviromental condition on the capacity of power lines, In: Acta Electrotechnica et Informatica. Vol. 17, No. 3 (2017), pp. 3-7. - ISSN 1335-8243.
[25] BEREŠ, M. and KOVÁČ, D., Digital pulse generator for multiphase bost converter, Acta Electrotechnica et Informatica. Vol. 14, No. 4 (2014), s. 46-51. - ISSN 1335-8243.