1. Ján ZBOJOVSKÝ[1], 2. Ľuboš ŠÁRPATAKY[1], 3. Miloš ŠÁRPATAKY [1]

Faculty of Electrical Engineering and Informatics, Technical University of Košice, Letná 9, 04200 Košice, Slovakia (1),
ORCID: 1. 0000-0003-4383-3996; 2. 0000-0002-2846-4419; 3. 0000-0003-2488-7008

doi:10.15199/48.2022.01.45

Shielding effectiveness of concrete in dependence of his electric properties

***Abstract**. Due to the constant increase in the number of electronic devices, there is a long-term impact of the electromagnetic field (EMF) on human health. In addition, on the other hand, the operation of electronic devices will be affected if the radiation level is too high. Shielding is used to reduce radiation exposure. The aim of this paper is therefore to examine the shielding effectiveness (SE) of concrete depending on the change of its relative permittivity. The paper performs simulations through a waveguide in the Ansys software. The investigated material "concrete" was placed in the middle of a waveguide with a thickness of 10 cm. The frequency range is from 1.6 GHz to 5 GHz. During the experiment, the shielding of wet and dry concrete were determined.*

Streszczenie.** Ze względu na stały wzrost liczby urządzeń elektronicznych istnieje długofalowy wpływ pola elektromagnetycznego (PEM) na zdrowie człowieka. Ponadto, z drugiej strony, zbyt wysoki poziom promieniowania będzie miał wpływ na działanie urządzeń elektronicznych. W celu zmniejszenia narażenia na promieniowanie stosuje się ekranowanie. Celem niniejszej pracy jest zatem zbadanie skuteczności ekranowania (SE) betonu w zależności od zmiany jego przenikalności względnej. W artykule przeprowadzono symulacje za pomocą falowodu w oprogramowaniu Ansys. Badany materiał „beton" umieszczono w środku falowodu o grubości 10 cm. Zakres częstotliwości wynosi od 1,6 GHz do 5 GHz. W trakcie eksperymentu wyznaczono ekranowanie betonu mokrego i suchego.* (Skuteczność ekranowania betonu w zależności od jego właściwości elektrycznych***)

Keywords: shielding effectiveness, concrete, simulation, electromagnetic field
Słowa kluczowe: skuteczność ekranowania, beton, pole elektromagnetyczne..

Introduction

The presence of sources of electromagnetic interference (EMI) due to the increase in the number of mobile phones, wifi devices, telecommunication stations, antennas, sensors for wireless communication and the Internet of Things (IoT) has exposed humanity to long-term radiation. According to the World Health Organization (WHO), human health will be affected by long-term exposure to strong electromagnetic (EM) fields [1,2]. In addition, it can also affect many medical devices that are sensitive to electromagnetic radiation. In this context, the development of new building materials capable of reducing the penetration of electromagnetic waves has become actual [3,4]. Each new material requires measurements and testing to determine its ability to shield the incident electromagnetic wave. At present, it is also necessary to find out which values of shielding effectiveness can be reached in building materials. In our case, concrete was selected for the experiment, and on the basis of available information on its dielectric properties [5,6], various conditions from dry to wet concrete were simulated, and then the shielding effectiveness was evaluated. In order to effectively attenuate the penetration of the electromagnetic field, the material should have good electrical conductivity [7]. Therefore, these progressive materials are combined or mixed with conductive materials.

Shielding effectiveness

Shielding is an important part of the equipment, both in terms of mutual interference and in order to protect the population from electromagnetic radiation. [8,9] If the value of the transmitted signal is set in logarithmic units, then the shielding effiectiveness SE is determined according to Equation (1) to (4):[18] [19]

(1) $$SE - |E_1| - |E_2|$$

(2) $$SE - |H_1| - |H_2|$$

(3) $$SE - |V_1| - |V_2|$$

(4) $$SE - |P_1| - |P_2|$$

where E_2 represents the intensity of the electric field at a certain point of the shielded area, E_1 the intensity of the electric field incident on the shielding barrier. H_2 is the intensity of the magnetic field at a certain point of the shielded area, H_1 the intensity of the magnetic field incident on the shielding barrier, V_2 is the wave voltage of the electromagnetic field, V_1 is the voltage of the wave of the electromagnetic field incident on the shielding barrier or wall. P_2 represents the power of the electromagnetic field at a certain point of the shielded area and P_1 the power of the electromagnetic field incident on the shielding barrier or wall.

Shielding effectiveness of various materials can be categorized as follows:

Table 1. Distribution of materials according to shielding effectiveness

Category of shielding effectiveness	SE [dB]
Insufficient shielding	0-10
Shielding for minimum requirements	10-30
Shielding sufficient for most common requirements	30-60
Very good shielding	60-90
Very high quality shielding	90-120

Material for experiment and calculation

As a material for experiment, "concrete" was chosen. In general, materials can be characterized by electrical permittivity ε, electrical conductivity σ, magnetic permeability μ and magnetic conductivity σ *. The frequency dependence of all these properties is called dielectric dispersion. Concrete is assumed to be a homogeneous, isotropic and lossless dielectric medium. The dielectric properties of a material can be used to determine other properties of the material, such as moisture content. For the experiment in our case, the data of the change of the relative permittivity of the concrete, available from [5,6], were used. There are two states when it is possible to consider concrete as dry (range of permittivity change from 2.5-7.5) and as wet concrete (range of permittivity change from 8.5-12) in both case with step 1.5. Shielding effectiveness calculations were performed in Ansys Electronics Desktop 2021 R1. A waveguide model with dimensions of 60x10x3 cm was made in the program. The

waveguide model is shown in Figure 1. The frequency range is from 1.6 to 5 GHz, with 0.10 GHz steps.
Shielding effectiveness is obtained by calculating the S parameter, namely S (2,1). S (2,1) is a parameter that represents how much radiation is transmitted from port 1 to port 2 [11] [12] [13] [16].

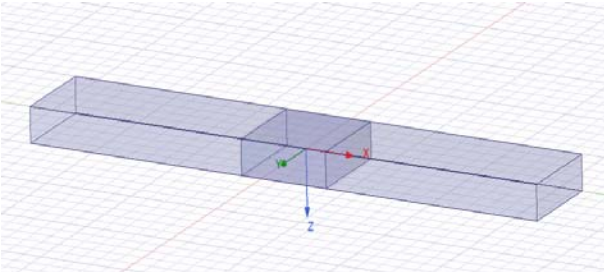

Fig.1. Model of waveguide

The SE is calculated according to:

(5) $$SE_{dB} = SE_{21\,without\ barier} - SE_{21\,with\ barier}$$

The essence of this relation is that the S (2,1) parameter is measured in a waveguide without a barrier, then the barrier is added and the S (2,1) parameter is measured again. Their difference will be the result, which represents the shielding effectiveness [10] [14] [15] [17].

Experiment and Results

First, simulations without barrier were performed to obtain the S (2,1) parameter. The next step was simulations with an inserted barrier, in our case concrete with a thickness of 10 cm. As it was mentioned, the frequency range for the simulations was from 1.6 to 5GHz. Then it was selected certain frequencies, for which the shielding effectiveness was compared, which can be seen in the following table. Relative permittivity in the simulations were changed with step 1.5.

Table 2. Frequencies for comparing the shielding effectiveness

Frequency [GHz]	Utilization
1.8	Mobile networks (2G)
2.1	Mobile networks (3G)
2.4	WiFi
2.6	Mobile networks (LTE)
5	WiFi

Following pictures shows the propagation of the electromagnetic wave though the dry concrete with relative permittivity of 2.5 and S(2,1) parameter

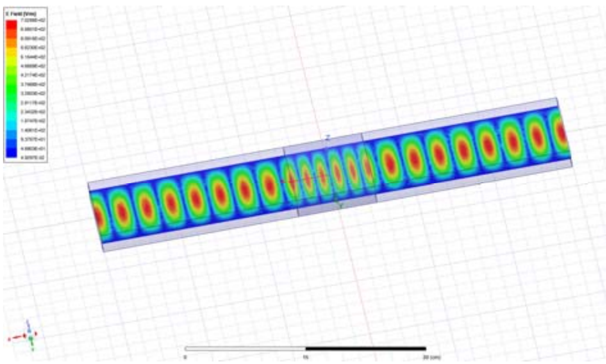

Fig.2. the propagation of the electromagnetic wave though the dry concrete with relative permittivity of 2.5.

The average value of the shielding effectiveness for the whole frequency range was 0.8956 dB, and the best value was at the frequency 1.6 GHz, and it was 5.1913 dB. According to the Table 1, Distribution of materials according to shielding effectiveness we can claim that it is insufficient shielding.

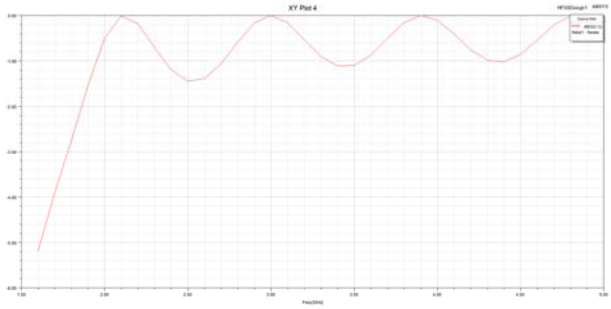

Fig.3. the The S(2,1) parameter of the dry concrete with relative permittivity of 2.5.

For comparison, with the resluts with the relative permitivity of 2.5, the next pictures are shown the propagation of the electromagnetic wave and the S(2,1) parameter of the concrete with relative permeability of 7.5.

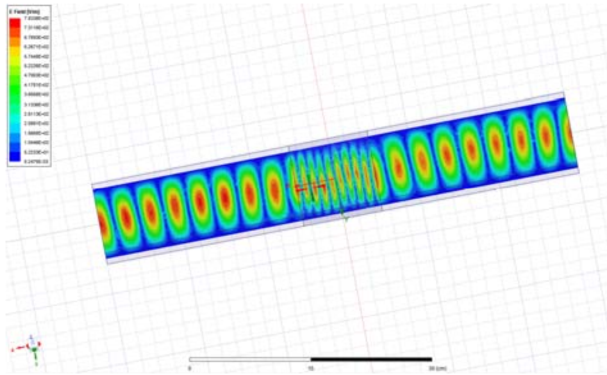

Fig.4. the propagation of the electromagnetic wave though the dry concrete with relative permittivity of 7.5.

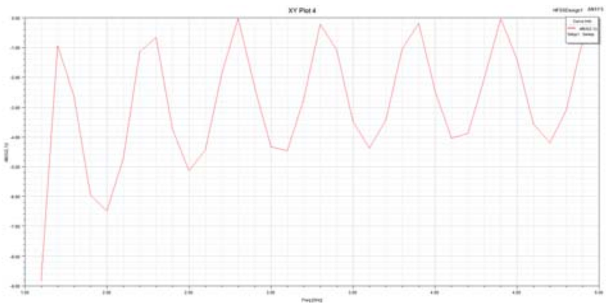

Fig.5. the The S(2,1) parameter of the dry concrete with relative permittivity of 7.5.

The average value of the shielding effectiveness for the whole frequency range was 2.8601 dB, and the best value was at the frequency 1.6 GHz, and it was 8.8176dB. According to the Table 1, Distribution of materials according to shielding effectiveness we can claim that it is insufficient shielding.

On the following pictures are shown the propagation of the electromagnetic wave though the wet concrete with relative permittivity of 8.5 and 12, and S(2,1) parameter.

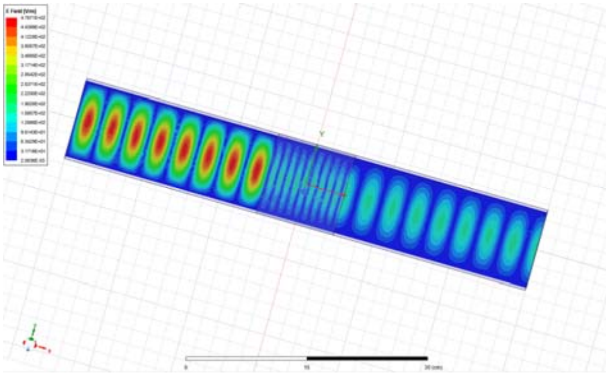

Fig.6. the propagation of the electromagnetic wave though the wet concrete with relative permittivity of 8.5.

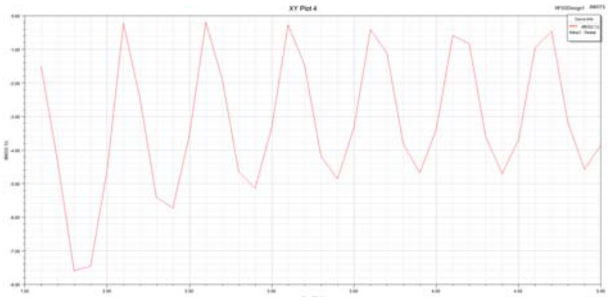

Fig.7. the The S(2,1) parameter of the wet concrete with relative permittivity of 8.5.

The average value of the SE for the whole frequency range was 3.2037 dB, and the best value was at the frequency 1.8 GHz, 7.5830 dB. According to the Table 1, Distribution of materials according to shielding effectiveness we can claim that it is insufficient shielding.

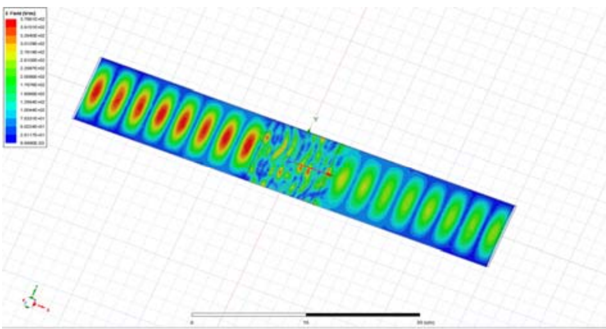

Fig.8. the propagation of the electromagnetic wave though the wet concrete with relative permittivity of 12

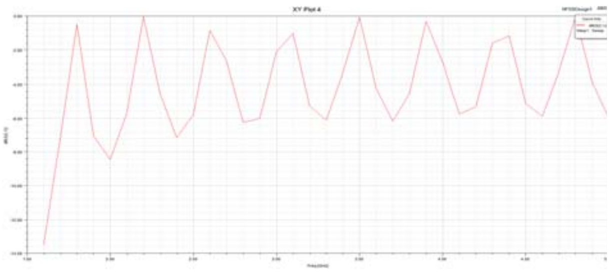

Fig.9. the The S(2,1) parameter of the wet concrete with relative permittivity of 12.

The average value of the SE for the whole frequency range was 4.2733 dB, and the best value was at the frequency 1.6 GHz, 13.4941 dB. According to the Table 1, Distribution of materials according to shielding effectiveness we can claim that it is insufficient shielding for the whole frequency range, but for the frequency of 1.6 GHz it is Shielding for minimum requirements.

Following tables shows the results from the simulations for the certain frequencies.

Table 3. Frequencies for comparing the shielding effectiveness of dry concrete

Freq [GHz]	**Shielding effectiveness [dB] in dependence of relative permittivity**					
	2.5	**3.5**	**4.5**	**5.5**	**6.5**	**7.5**
1.8	2.7617	0.0107	4.8159	5.8738	1.6329	2.6256
2.1	0.0131	3.0152	1.8934	1.2193	5.3717	4.7378
2.4	1.1997	0.8923	2.0261	3.8123	0.1530	3.7330
2.6	1.3913	0.2285	3.1857	0.1978	3.5078	4.4506
5	0.3156	0.4878	0.0005	1.6804	3.6077	0.3452

Table 4. Frequencies for comparing the shielding effectiveness of wet concrete

Freq [GHz]	**Shielding effectiveness [dB] in dependence of relative permittivity**				
	8.5	**9.5**	**10.5**	**11.5**	**12**
1.8	2.6256	7.5830	8.7018	6.5340	0.8796
2.1	4.7378	0.2367	3.8381	7.2970	7.0980
2.4	3.7330	5.7305	2.6017	1.1000	6.1070
2.6	4.4506	0.1989	3.9608	6.3273	3.6614
5	0.3452	3.8498	2.7382	3.6817	3.6002

On the following pictures are shown the dependence of shielding effectiveness from the relative permittivity of dry, and wet concrete.

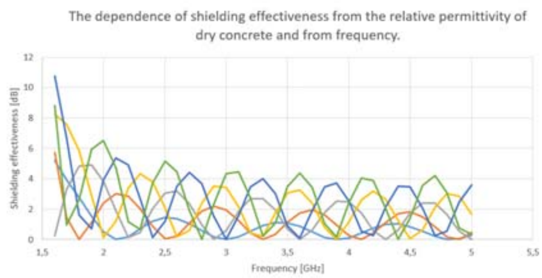

Fig.10. The dependence of shielding effectiveness from the relative permittivity of dry concrete and from frequency.

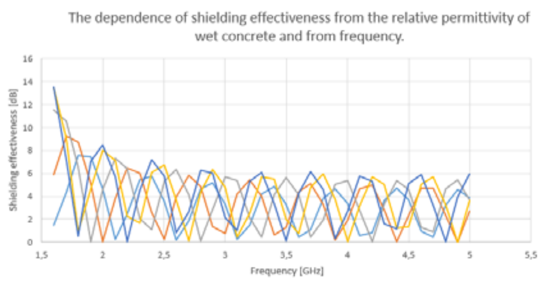

Fig.11. The dependence of shielding effectiveness from the relative permittivity of wet concrete and from frequency.

Conclusion

The aim of this paper was to determine the values of the shielding effectiveness of building materials, specifically concrete, through simulation. For these purposes, a waveguide model was created, for the frequency range from 1.6 to 5 GHz. The main problem in simulations of materials is the knowledge of their electrical properties, such as relative permittivity. For the “concrete” material, these values were obtained from available sources, and these values vary depending on the moisture content of the material. Therefore, simulations were performed for the case of dry concrete with a change of relative permittivity in the range from 2.5 - 7.5, with step 1.5. The second case was the material "wet concrete" with a change of relative permittivity in the range from 8.5 - 12, also in steps of 1.5 GHz. Subsequently, a comparison of the shielding effectiveness values for the selected most used frequencies was performed. At a frequency of 2.1 GHz, the best values of shielding effectiveness were achieved by "wet" concrete with a relative permittivity of 10.5, namely 7.2970 dB. On the contrary, the smallest value, 0.0131 dB, had "dry" concrete at a relative permittivity of 2.5. At 2.4 GHz, the highest value was at a relative permittivity of 12, SE= 7.1460 dB, and the lowest value at 3.5, SE= 0.8923 dB. For the 2.6 GHz frequency, the values were as follows: highest value SE = 6.3273 dB at permittivity 10.5 and lowest value SE = 0.2285 dB at permittivity 3.5. At 5GHz, the highest value of SE = 5.9608 dB at permittivity was 12, and the lowest value of SE = 0.3156 dB at permittivity of 2.5. Except for this last value, we can all classify them in the category of insufficient shielding. The experiment confirmed the weak shielding effectiveness of concrete. Another direction of the experiments is the way of mixing building materials with others materials, such as graphite, or some conductive materials.

This work was supported by project: FEI-2021-74, Research of the influence of selected building materials and elements in order to evaluate their interaction with high-frequency electromagnetic radiation.

***Authors**: Ing. Ján Zbojovský, PhD. Department of Electric Power Engineering, Faculty of Electrical Engineering and Informatics, Technical University of Košice, Letná 9, 04200 Košice, Slovakia, E-mail: jan.zbojovsky@tuke.sk; Ing. Ľuboš Šárpataky, Department of Electric Power Engineering, Faculty of Electrical Engineering and Informatics, Technical University of Košice, Letná 9, 04200 Košice, Slovakia, E-mail: lubos.sarpataky@tuke.sk; Ing. Miloš Šárpataky, Department of Electric Power Engineering, Faculty of Electrical Engineering and Informatics, Technical University of Košice, Letná 9, 04200 Košice, Slovakia, E-mail: milos.sarpataky@tuke.sk*

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