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Influence of Electromagnetic Shield on the High Frequency Electromagnetic Field Penetration through the Building Material

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This paper studies how to protect people against electromagnetic radiation inside a building. Widespread usage of the mobile communication led to building of more and more new GSM base-station antennas. These antennas are often placed in the areas with high population density. These antennas emit electromagnetic radiation in standard mobile operator frequencies, i.e. 0.9, 1.8 and 2.1 GHz. Many studies have shown potential biological and thermal effects of GSM electromagnetic fields, therefore people are concerned about their health. Electromagnetic wave does not penetrate the wall of the building as a whole. A small part of the wave is reflected and a small part is absorbed by the building material. In this paper the penetration of electromagnetic waves through the commercially available building materials is measured with specific focus on frequencies of 0.9, 1.8, and 2.1 GHz. Next, the surface of the chosen building material was coated with a magnetic conductive paint in order to improve the shielding effect of the building material. The results of experiment show how the electromagnetic shield reduces the penetration of electromagnetic waves through the building wall.

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1. Introduction

The physical interaction of an electromagnetic field with a biological object is a complex process, where the amount of absorbed energy in a tissue is frequency dependent. Depending on the ratio of the dimensions of a biological object to the wavelength, the electromagnetic spectrum is divided into three groups: under 30 MHz, where a wavelength is greater than the dimensions of the biological object, from 30 MHz to 10 GHz, where the wavelength is comparable to the dimensions of the body and over 10 GHz, where the wavelength is considerably smaller than the dimensions of the biological object. In the interval from 30 MHz to 10 GHz there is an absorption maximum at which the body absorbs more energy than it is passing through its cross-section. Any biological object has a resonant frequency at which maximum absorption occurs [1].

2. Shielding of electromagnetic field

A shielding enclosure is used for attenuation of electric, magnetic, and electromagnetic (EM) fields in order to reduce their impact on equipment, devices and biological systems, located behind a protective cover. The protective cover is placed between the source of electromagnetic waves and the protected unit. The cover reduces the intensity of the applied electric field E_1 and magnetic field H_1 to the values E_2 and H_2, which can be measured behind the shielding enclosure. The shielding enclosure has the same effect as moving the protected object away from the source of EM waves.

Frequencies of EM field, conductivity of the shielding material, dielectric permittivity and magnetic permeability of the shielding material and the thickness of the shielding barrier influence the shielding effectiveness. The overall shielding effectiveness (SE) consists of EM wave reflection coefficient R from the shielding barrier and the absorption coefficient A of the waves in the barrier material. Multiple reflections inside the barrier as well as by external walls are ignored [2].

The wave equations used for calculation of the wave propagation in the long transmission lines can be used to determine the relation between the reflection and the absorption coefficient, the characteristics of EM field and the properties of the barrier material. The intensity of magnetic field H_{inc} of the incidence wave on the shielding barrier is given by [3]:

$$|H_{inc}| = \frac{|E_{inc}|}{Z_0}. \qquad (1)$$

E_{inc} is the intensity of the electric field of the incidence wave and Z_0 is the impedance of the space through which the wave propagates. If the electromagnetic waves are propagating in air, where $\mu_r = 1$ and $\varepsilon_r = 1$, then Z_0 is calculated as: $Z_0 = \sqrt{\mu_0/\varepsilon_0}$.

When the incidence wave hits the barrier, a part of the incidence wave is reflected from the barrier and a part of the incidence wave is absorbed by the barrier. The rest of the incidence wave passes through the barrier to the

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other side of the barrier. The absorbed magnetic field by the barrier can be calculated as

$$|H_{abs}| = \frac{|E_{abs}|}{Z_S}, \quad (2)$$

where H_{abs} and E_{abs} are the intensities of the magnetic and electric field absorbed by the shielding barrier and Z_s is the impedance of the barrier material, which may be defined as [4]:

$$Z_S = \sqrt{\frac{\mathrm{j}\omega\mu}{\sigma + \mathrm{j}\omega\varepsilon}} \quad (3)$$

In Eq. (3), µ is the absolute permeability, ε is the absolute permittivity and σ is the conductivity of the shielding material. Since it is sometimes difficult to determine these parameters of the barrier material, the SE of the shielding barrier is frequently determined experimentally. If the value of the transmitted signal is expressed in logarithmic units, the SE is determined according to IEEE 299-2006 Standard Method for Measuring the Electromagnetic Shielding Effectiveness of enclosures [2] as

$$SE = P_1 - P_2, \quad (4)$$

where P_1 is a power intensity captured by a receiving antenna without the shielding barrier and P_2 is the power intensity measured at the same place in the presence of the shielding barrier. If the values are measured in the base units [V/m] and [mA/m] then the formula for calculating SE may be expressed either in the terms of an electric field or in the terms of a magnetic field using the following equations:

$$SE = 20\log\frac{E_1}{E_2};\ SE = 20\log\frac{H_1}{H_2}, \quad (5)$$

where E_1 and H_1 are the intensities of the electric field and the magnetic field measured using the receiving antenna in the absence of the shielding barrier, while E_2 and H_2 are the intensities of the electric and the magnetic field measured in the presence of the barrier.

3. Experimental setup

In order to protect inhabitants against the electromagnetic field, various techniques are used. For example, the walls are built from reinforced concrete, windows are fitted with conductive films or walls are coated with a conductive coating from inside or outside. In this paper, the last form of protection is evaluated. Two semiconductive paints R762 and HSF54 with different surface conductivity were tested.

As a base material there was used a particleboard. Its advantage is that the material is dielectric with high surface resistance. Its SE of high-frequency electromagnetic fields is very low. Screening layer was applied on one side of the base board by a paint-roller. Physical characteristics of the base board sample (S) and the sample with the R762 paint (S1) and the HSF54 paint (S2) are given in Table I. Values of relative permittivity ε_r and dissipation factor tanδ for frequencies 0.8, 0.9, and 1.0 GHz were measured by impedance analyzer KEYSIGHT E4991B. The thickness of the board with a surface coating d was measured with a micrometer. Surface resistance ρ_s of the material was measured by KEITHLEY 617.

TABLE I

Physical characteristics of the shielding barriers.

Sample	S		S1-R762		S2-HSF54	
f [GHz]	ε_r	$100\tan\delta$	ε_r	$100\tan\delta$	ε_r	$100\tan\delta$
0.8	16.6	1.105	17.7	0.12	67.9	0.8
0.9	17.5	1.235	18.6	0.12	64.9	0.85
1	18.6	1.399	19.8	0.12	53.3	0.56
d [mm]	3.2		3.6		3.4	
ρ_s [Ω]	5.10^{11}		$1.5.10^4$		350	

The measurements using two antennas (transmitting and receiving) took place in an anechoic chamber. Measuring bloc-diagram is shown in Fig. 1. Antenna type horn RF spin DRH18-E with 50 Ω impedance and maximum input power 100 W was used as a transmitting antenna. The antenna was exciting by analog signal generator Agilent MXG N5183A. The transmitting signal was received by receiving antenna Hyper LOG 60100 and the electric and the magnetic component of electromagnetic field was processed by Spectran HF 60105.

First, the calibration and the measuring of the received signal without a barrier were realized (see Fig. 1a). Next, the barrier was placed between the two antennas (see Fig. 1b). The receiving signal was measured using three different types of barrier. Barriers with electroconductive paints were grounded during the measurement. Attenuation of electric field intensity E [V/m], magnetic field intensity H [mA/m] and the SE (dB) was measured in the frequency range from 0.8 to 9.0 GHz with a step of 0.1 GHz.

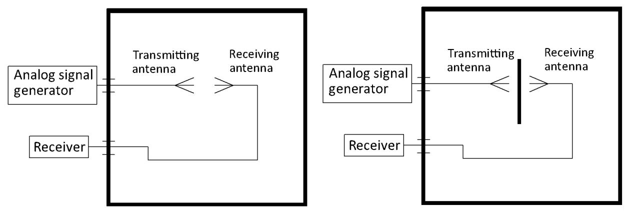

Fig. 1. Measuring bloc-diagram of electromagnetic field SE: (a) without a barrier, (b) with a barrier.

The sample with the best SE was chosen for the next experiment which consisted of the placing a brick wall between the transmitting and the receiving antennas. The wall was built using 0.3 m thick Porothem clay blocks. The transmitting antenna and the signal generator were used the same as in the previous experiment. On the receiving side, antenna horn R&S HF907 with an input impedance of 50 Ω and the maximum input power of 300 W was used. Signal attenuation of the electromagnetic field was studied using a spectrum analyzer Agilent MXE EMI Receiver N9038A. Shielding effectiveness of the brick wall was measured in the frequency range from 0.8 to 9 GHz with a step of 0.01 GHz.

4. Results and discussion

The electrical component of the transmitted EM wave registered by the receiving antenna is shown in Fig. 2. The figure compares the intensity of the electric field recorded by the receiving antenna without a barrier and in the case of using three different shielding barriers. It can be seen that the board without a paint does not attenuate the transmitted wave, the sample S1 attenuates the wave only minimally and the sample S2 achieves the best results. The magnetic component of the transmitted EM wave is shown in Fig. 3, while the SE for all three barriers is depicted in Fig. 4. As it can be seen from Figs. 2–4, the best results were achieved by the sample S2. The highest reduction of the EM field was recorded for the sample with the highest conductivity. Therefore, this sample was chosen for the experiment which simulated using of shielding coatings in the area of civil engineering.

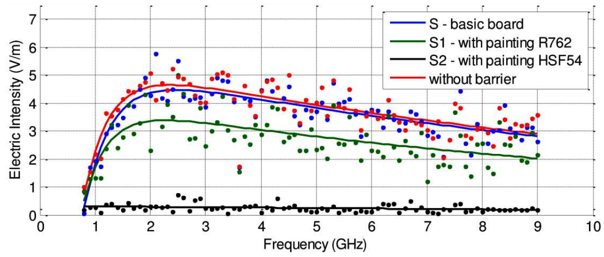

Fig. 2. Attenuation of an electrical component of an electromagnetic field.

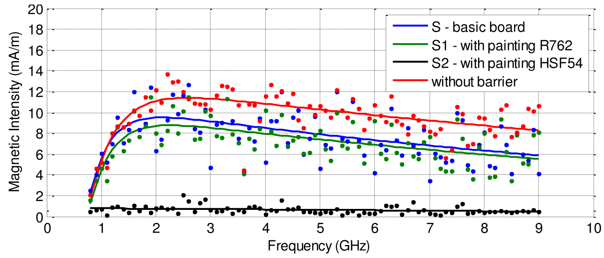

Fig. 3. Attenuation of a magnetic component of an electromagnetic field.

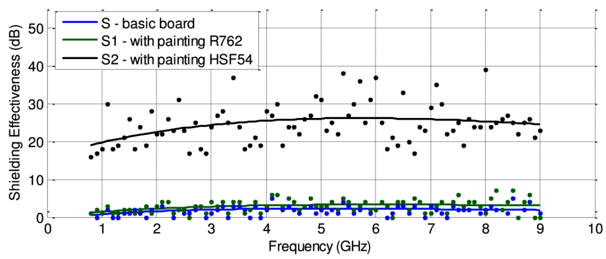

Fig. 4. Shielding effectiveness of the barriers.

The chosen sample with a conductive painting HSF54 (S2) was placed in front of the brick wall, imitating the outdoor shielding coating, and behind the brick wall, imitating the indoor shielding coating. Results, presented in Fig. 5, show that the SE of a brick wall without a barrier for frequencies up to 2.2 GHz was very small, i.e. no more than 4 dB. For higher frequencies, the shielding effectiveness raised up to 22 dB. SE of the brick wall with a painted sample significantly increased and reached up to 40 dB for high frequencies. Positioning the painted sample in front of the wall or behind the wall did not have a significant influence on the SE. The SE at the frequencies of 0.9, 1.8, and 2.1 GHz, which are used in mobile networks, for the wall without a barrier and with the barrier in front of and behind the wall is shown in Table II.

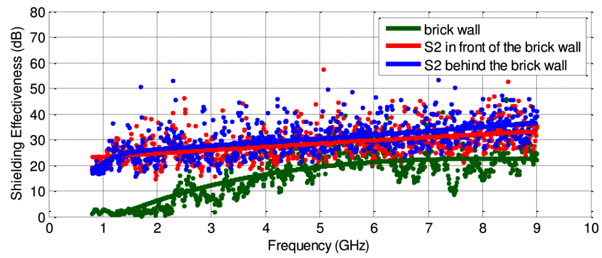

Fig. 5. Shielding effectiveness of the brick wall with and without a shielding barrier.

TABLE II

Shielding effectiveness of barriers for mobile frequencies

f [GHz]	SE_{brick} [dB]	$SE_{S2front}$ [dB]	$SE_{S2behind}$ [dB]
0.9	2	22	18
1.8	3	25	19
2.1	4	22	25

5. Conclusions

The main focus of this paper is the transition of electromagnetic waves through a shielding barrier. Two different paint coatings on the surface of the base board were chosen as barriers. Results showed that the sample with the higher conductivity and the bigger value of relative permittivity reduced the incident on the barrier wave the most. Special focus was given on the frequencies used by mobile networks operators and the values of shielding effectiveness measured for these frequencies are shown in Table II. The range of measured frequencies was extended up to 9 GHz as currently there are numerous devices broadcasting at these frequencies and we can expect that the number of these devices will only increase in the future. Therefore, it is important to think about the protection of the population against the electromagnetic fields at wide range of frequencies.

Acknowledgments

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