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Measuring shielding effectiveness of electromagnetic field for degradation shielding paint

***Abstract**. This paper deals with measuring the shielding efficiency of a shielding coating. The paper describes the physical properties of the coating, such as εr, tgδ, ρS, which were measured at a frequency of 1 GHz. This measurement was performed in the frequency range from 1 GHz to 5 GHz in 100 MHz steps. Measurements were performed in an anechoic chamber to prevent external influences. The examined sample was measured every year for 4 years from the initial coating. The measurements were focused on whether the shielding coating loses its shielding ability after years. The results show that the decrease in shielding effectiveness was 3 - 6 dB during 4 years. The measurement error is 1.5 - 2.5 dB. It follows that the decrease in shielding ability is not rapid.*

***Streszczenie.** Artykuł dotyczy pomiaru skuteczności ekranowania powłoki ekranującej. W pracy opisano właściwości fizyczne powłoki, takie jak εr, tgδ, ρS, które zostały zmierzone przy częstotliwości 1 GHz. Pomiar ten wykonano w zakresie częstotliwości od 1 GHz do 5 GHz w krokach co 100 MHz. Pomiary przeprowadzono w komorze bezechowej, aby zapobiec wpływom zewnętrznym. Badana próbka była mierzona corocznie przez 4 lata od pierwszego powlekania. Pomiary koncentrowały się na tym, czy powłoka ekranująca po latach traci zdolność ekranowania. Wyniki pokazują, że spadek skuteczności ekranowania wyniósł 3 - 6 dB w ciągu 4 lat. Błąd pomiaru wynosi 1,5 - 2,5 dB. Wynika z tego, że spadek zdolności osłony nie jest gwałtowny. (**Pomiar skuteczności ekranowania pola elektromagnetycznego pod kątem degradacji farby ochronnej**).*

Keywords: electromagnetic field, shielding, non-reflection chamber.
Słowa kluczowe: pole elektromagnetyczne, ekranowanie, komora bezodbiciowa.

Introduction

In today's rapidly evolving society, more and more attention is being paid to the concept of electromagnetic fields. More and more, this concept is penetrating the lay public and the fact that the general lay public is interested in the possible impact of the electromagnetic field on the human body. With the advent of the 5G network, a lot of disinformation was created, which is of interest to the general lay public. This is mainly due to concerns about the possible effects of the electromagnetic field [1] [2].

In the professional and scientific community, research focuses on the influence of the electromagnetic field on biological effects, but the results of research vary considerably. Not every research can unambiguously confirm the negative impact of the electromagnetic field. This is because there are a number of other factors that affect research results [3] [4].

Electric, magnetic and electromagnetic fields that can have adverse biological effects can be collectively referred to as electrosmog. These electromagnetic fields are also more appropriately referred to as electromagnetic pollution [1] [5] [6] [7].

In Slovakia, separate legal acts apply to protect the population and employees from the electromagnetic field. Both legal acts are in line with the recommendations of the European Union. Failure to exceed the action values will guarantee that the exposure limit values will not be exceeded. In addition to binding legal documents, there are also technical standards that are less strict and non-binding recommendations of independent experts, which are extremely strict [8] [9] [10].

Electromagnetic field effect

In recent decades, the effects of radio frequency radiation on living organisms have been addressed, among others, by the World Health Organization (WHO) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP). These set limiting criteria for electrical equipment due to their electromagnetic compatibility with a view to minimizing adverse effects on humans, but only after a number of negative responses, the number of which began to increase. The result of the interaction also depends on the physico-chemical properties of the organism, especially on the dimensions, weight, nature of the surface (clothing), layer thickness (skin - fat layers - muscles), water content, immediate state of the organism (health and mental) [11] [12].

In principle, two main groups of electromagnetic field effects are distinguished:

- Thermal effects - are given by an increase in temperature due to absorbed EM energy
- Non-thermal effects - direct effects of the electromagnetic field

However, this division is possible only on a theoretical level, in real practice these two types of effects of the EM field are practically inseparable. The thermal effects of EM fields are already very well mapped and widely used in medicine for various therapeutic applications in oncology, cardiology, urology, surgery, physiotherapy, etc.

At present, it is possible to apply a shielding coating to the walls, which prevents the penetration of the electromagnetic field. In the past, we have focused on measuring the effectiveness of shielding. Shielding effectiveness is an indicator of the shielding quality of the electromagnetic field. In our experiment, we focused on measuring the shielding effectiveness of this coating after a year, two, three and four and compared the shielding ability of the material 4 years ago. 4 years ago, the coating was applied twice [11] [13] [14] [15].

Measuring shielding effectiveness

Electromagnetic shielding can be characterized by the so-called shielding coefficient *Ks*. It is the ratio of the intensity of the electric field *E2* (or magnetic field *H2*) at a certain point of shielding the space to the intensity *E1* (*H1*) of the field incident on the shielding partition. *A* better indicator of shielding is the shielding effectiveness of the *SE*. According to [8] shielding effectiveness is the sum of the reflection R, multiple reflection B and absorption A of electromagnetic field derived as [6] [16]:

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

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

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 (3) without the multiple reflections *B* [6] [17].

(3) $$SE = A + R$$

From the relationships for the shielding effectiveness, reflection and absorption of the electromagnetic field, it can be seen that the shielding effectiveness depends not only on the frequency but also on the physical properties of the shielding material. The problem, however, is that these properties change in the observed frequency band and are not constant. If these properties did not change, it would be relatively easy to calculate the shielding effectiveness, reflection and absorption of the electromagnetic field. However, for the reasons mentioned above, it is necessary to measure these values [6] [18] [19] [20].

Evidence of a change in the permittivity property is also provided by subsequent research, which confirms this statement. Process which causes orientation of electric dipole moments within dielectrics into a direction of an outer field is known as an Electrical polarization. Arrangements of centres of gravity positive and negative charge particles have significant influence on the polarization. The next important influence has an amount of impurities and type of a bond between molecules. The polarization mechanisms can be divided in to the three groups based on force of bonds in a dielectric structure. Deformation polarizations occur in dielectrics with strong bond of charge particles in atoms, molecules or crystals. Relaxation polarizations occur within dielectrics with week forces between molecules especially in gases and liquids. The last type is migration polarizations caused by free charge particles in a dielectric. If dielectric is subjected to the outer electric field, the particles are focused in areas of imperfections or irregularities and space charges are developed. The main differences of the polarization types are physical processes within material structures and a value of relaxation (stabilizing) time [21] [22].

Following contributions from K. S. Cole and R. H. Cole, one of the methods for studying the frequency dependence of complex permittivity of dielectric materials has been by the use of Cole-Cole diagrams. Such a diagram is the plot between real and imaginary components (ε' and ε") of complex permittivity over the entire frequency range. Subsequently, Cole-Cole plots have been used by researchers for characterizing different materials and composites including pure as well as dielectric mixtures, ferrite films, ionic liquids, cable insulating oil, and polar liquids [23] [24].

Preliminary investigations on how Cole-Cole diagram can be used to demonstrate the changes in material structure and individual polarization mechanisms in dielectric liquids were reported by S. Martin et al.. Possibility of application of the Cole-Cole model for analysis of dielectric response measurement results on transformer oil paper insulation was initiated by S. Wolny et al. . The above investigations however, did not consider the distributed nature of the relaxation processes [6] [16] [25] [26].

Experiment

The experiment was performed under the same conditions in an anechoic chamber. The experiment was performed in the frequency range from 1 GHz to 5 GHz. With this experiment, we wanted to find out whether the shielding coating degrades over the years and whether the shielding effectiveness of the electromagnetic field changes.

The temperature in the anti-reflection chamber is 22 - 24 degrees Celsius and humidity 43% - 45%. The parameters of shielding paint we can see in Table 1. The parameters measuring we performed for frequency 1 GHz.

Table 1. The parameters of shielding paint

	Frequency 1 GHz
ε_r[-]	53,3
tgδ[-]	$0{,}56.10^{-2}$
ρ_S[Ω]	350

This workplace consists (Fig.1 and Fig.2) 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, 26].

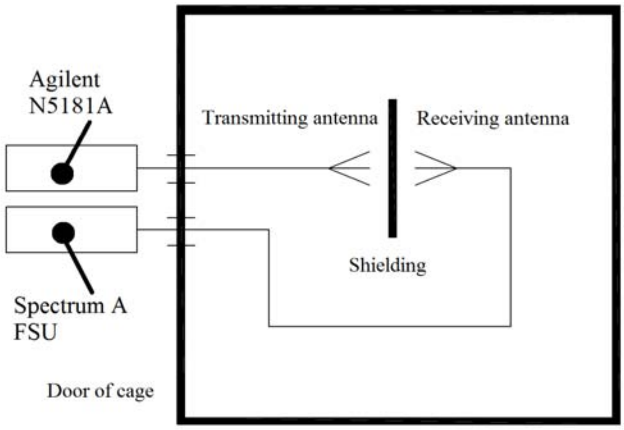

Fig.1. Workplace for measuring shielding effectiveness

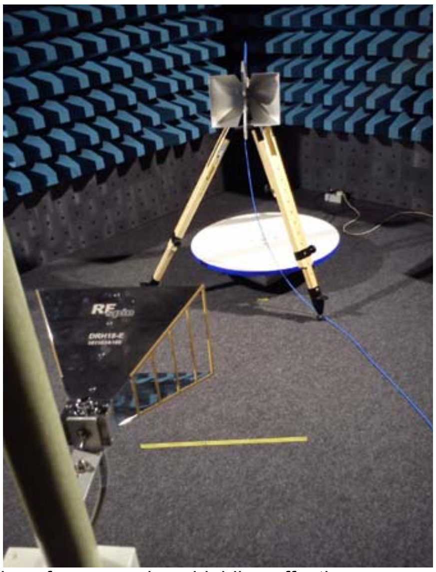
Fig.2. Workplace for measuring shielding effectiveness

The coated sample was placed in a room for 4 years and exposed to normal environmental influences. The sample was applied to the plate. Prior to the measurement itself, the shielding effectiveness of the board itself was measured. The shielding effectiveness of the board itself was subtracted from the total shielding effectiveness (board

+ coating). The measurement was performed under the same conditions. The measurement was repeated 10 times and an automated system was created for the purpose of this measurement in the Keysight VEE program.
The software automatically set the monitored frequency and amplitude of the transmitted signal on the pulse generator. At the same time, he read the value of the amplitude of the receiving signal at this set frequency on the spectrum analyser. The software saves the data from the set frequency and the received signal to a file and to the cloud. A view of the created software can be seen in Fig. 1.

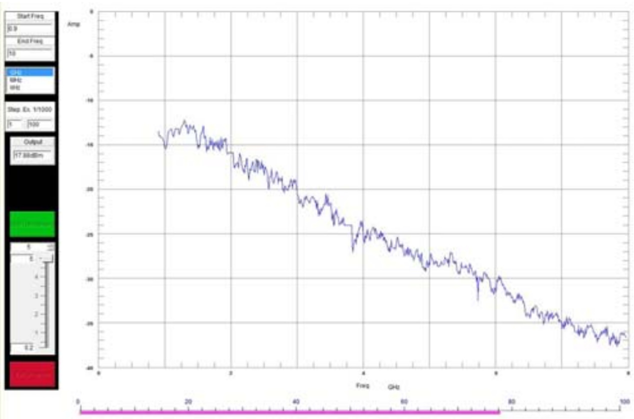

Fig.3. Software for processing data

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From the shielding effectiveness results, the average value at each monitored frequency was calculated. Figure 4 shows six dependencies. The solid line shows the course of the shielding effectiveness 4 years ago. The measurement was then performed immediately after the coating had dried. Other waveforms show the shielding effectiveness in the monitored frequency range after one, two, three and four years. From the results it is possible to observe a decrease in the shielding effectiveness in the whole frequency range. The decrease in shielding effectiveness in the monitored frequency range after four years is approximately 3-8 dB. As the frequency increases, the decrease in shielding effectiveness also increases slightly. As could be expected, the longer the coating is applied, the lower its shielding ability.

The coating manufacturer states that after two coats, the coating achieves an attenuation of approximately 50 dB at a frequency of 1 GHz. These values were confirmed by experiments 4 years ago. At the same time, another experiment confirmed that over the years, these values gradually decrease, but not rapidly. This statement applies in the whole frequency range from 1 GHz to 5 GHz.

Conclusion and discussion

This paper was focused on repeating the measurement, which was performed 4 years ago. The authors set out to measure the shielding effectiveness of the electromagnetic field for a shielding coating. This experiment was performed one year, two, three and four years after the first application. The task was to find out whether the shielding effectiveness of the electromagnetic field of the shielding coating changes over the years.

The results show that the shielding effectiveness of the shielding coating decreased after 4 years. In the frequency band from 1 GHz to 5 GHz, a decrease in shielding effectiveness of 3-6 dB was recorded. However, the shielding coating still serves as a shielding material. It should be noted that the measurement error was 1.5 - 2.5 dB, which also affected the accuracy of the results. The decrease in shielding effectiveness could be caused, for example, by degradation of the material from which the shielding coating is formed. The second reason could have been contamination of the paint, which is a common phenomenon in practice. On the other hand, in practice, a conventional wall paint is applied to this coating to prevent contamination of the coating.

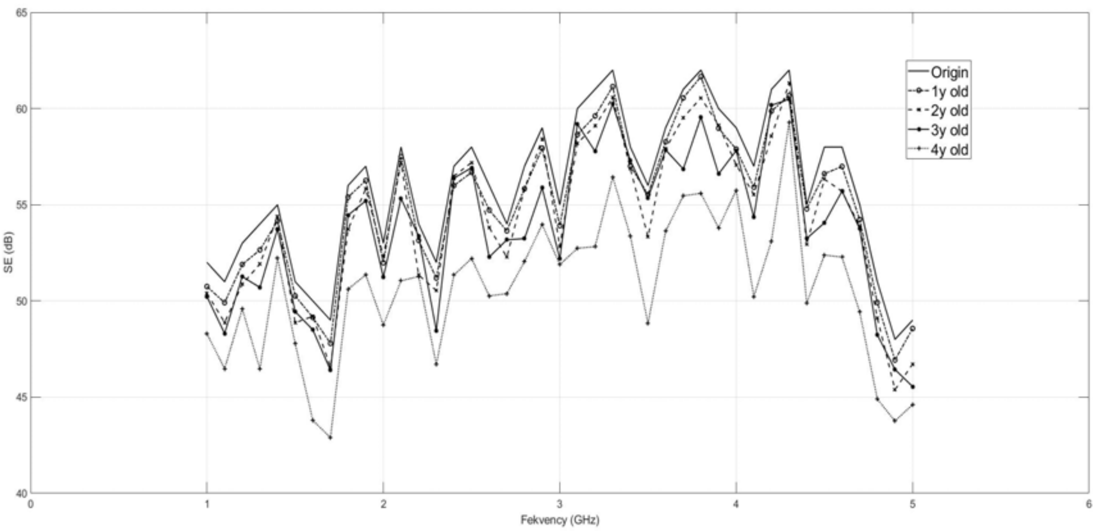

Fig.4. Shielding effectiveness depending on frequency range

It is possible to assume that this gradual decline in shielding effectiveness will continue over the years, but we do not expect it to be a rapid decline. On the other hand, by adding another layer after years, we will increase the shading effectiveness again.

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