Charcoal-Containing Microwave and Infrared Electromagnetic Shields with an Orderedly Structured Surface Layer Based on Foiled Material

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***Abstract*— The authors proposed the low-cost technologies for manufacturing electromagnetic shields. The paper contains the description of the proposed technologies. The shields manufactured according to the proposed technologies have three layers. The first (outer) layer consists on the set of orderedly structured 3D-elements. These elements have the shape of classical Archimedes spiral, loop or Mobius strip). These elements made from aluminum-containing foiled polymer material. The second (intermediate) layer is powdered activated charcoal particles impregnated by sodium chloride aqueous solution with a concentration of 35.0±1.0% and fixed between the fragments of self-adhesive polymer film. The third (inner) layer is aluminum aluminum-containing foiled polymer base. The paper also contains the description of the established regularities of changes of effective absorption bandwidth in the frequency range 2.0–17.0 GHz of the electromagnetic shields manufactured according to the proposed technologies depending to the shape of 3D-elements contained on their first (surface) layers. According to these regularities, the effective absorption bandwidth of the electromagnetic shields the first (inner) layers of which contains 3D-elements with the shape of classical Archimedes, loop or Mobius strip spiral achieves 8.0, 7.5 or 11.5 GHz respectively. Moreover, the paper also contains the description of the established regularities of changes of electromagnetic radiation reflection coefficient values in the infrared range such shields depending to the shape of the indicated elements. According to these regularities, the electromagnetic radiation reflection coefficient value in the infrared range of the electromagnetic shields the first (inner) layers of which contains 3D-elements with the shape of classical Archimedes, loop or Mobius strip spiral achieves 72.0, 86.0 and 78.0 % respectively. Electromagnetic shields manufactured according to the proposed technologies can be used for the manufacture of the panels for the functional zoning of rooms where electronic devices are located that are sensitive to the effects of microwave or thermal noises.**

***Keywords*— charcoal, electromagnetic shield, foiled material, infrared radiation, microwave radiation.**

I. Introduction

Electromagnetic shields are widespread materials nowadays. This is because [1–3]:

– there are many electronic devices which are the sources of microwave radiation;

– microwave radiation could be the interference for the different devices (in privacy, human life support devices, devices for information processing, monitoring devices etc.);

– some devices for speech information interception are based on use microwave radiation.

So, electromagnetic shields (in privacy, microwave absorbers) are one of the means with use of which it's possible to solve the medical, technical, information security and ecological problems [4–6]. Due to this fact

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electromagnetic shields (in privacy, microwave absorbers) development and improvement is of the modern scientific scopes. Electromagnetic shields development is closely connected with the synthesis new materials reducing the microwave radiation energy by its transforming in the heat. Electromagnetic shields improvement is closely connected with their structure modification (adding extra layers, changing the surface shape). The presented paper contains the results of the work targeted on the improvement electromagnetic shields based on activated charcoal. Such work was based on the research results presented in the papers [7–10]. According to results presented in the paper [7], electromagnetic shields based on activated charcoal impregnated with sodium chloride aqueous solution are characterized by high efficiency and narrower effective absorption bandwidth compared with electromagnetic shields based on activated charcoal impregnated with calcium or sodium chloride aqueous solution.

The hypothesis about possibility to improve electromagnetic shields based on activated charcoal impregnated with sodium chloride aqueous solution and to extend their effective absorption bandwidth was made according to the results presented in the papers [8–10]. The supposed improvement of the marked shields within the framework of the hypothesis is based on the adding in their structure surface layer containing the set of 3D-elements made from the foiled material and characterized by one of the following shape: classical Archimedes spiral, loop, Mobius strip.

In general, the aim of the work was to establish the regularities of changes of effective absorption bandwidth of the improved electromagnetic shields based on activated charcoal impregnated with sodium chloride aqueous solution depending to the shape of 3D-elements contained on their surface layer. Moreover, this work also was aimed on the establishment of regularities of changes of electromagnetic radiation reflection coefficient values in the infrared range such shields depending to the shape of the indicated elements. The second aim has been set in course of the presented research due to the fact that there are many electronic devices nowadays which are sensitive to thermal noises. Due to this fact the development materials protecting devices from such noises are urgent scientific and practical problem [11].

II. Materials and Methods

A. *The Proposed Technology*

Taking into account the proposed hypothesis, three technologies for manufacturing of improved electromagnetic shields based on activated charcoal impregnated with magnesium chloride aqueous solution are proposed.

The first of the technologies (hereinafter referred to as Technology 1) includes the following operations.

1. Formation of the first layer of the shield.

1.1. Cutting off two identical fragments from a roll of synthetic non-woven fibrous material, the length, width and shape of which are determined by the requirements for the length, width and shape of the shield being manufactured.

1.2. Cutting off identical rectangular fragments from a roll of aluminum foil to form 3D spiral elements.

1.3. Formation of identical 3D spiral elements from aluminum foil fragments obtained as a result of the implementation of operation 1.2, using a stencil plate containing depressions, the shape of which repeats the shape of the classical Archimedes spiral.

1.4. Distribution of 3D spiral elements formed as a result of the implementation of operation 1.3, with a step of 1.0 cm on the surface of one of the fragments of synthetic non-woven fibrous material cut as a result of the implementation of operation 1.1.

1.5. Placing the second of the fragments of synthetic non-woven fibrous material cut as a result of the implementation of operation 1.1, on top of the set of 3D spiral elements made of aluminum foil formed as a result of the implementation of operation 1.4.

1.6. Heat pressing of the structure obtained as a result of the implementation of operations 1.1–1.5.

2. Formation of the second layer of the shield.

2.1. Cutting two identical fragments from a roll of self-adhesive polymer film, the overall dimensions and shape of which are determined by the requirements for the overall dimensions and shape of the shield being manufactured.

2.2. Impregnation of powdered activated charcoal with sodium chloride aqueous solution with a concentration of 35.0±1.0%.

2.3. Uniform distribution of a layer of 0.3±0.1 cm thick particles of powdered activated charcoal impregnated with sodium chloride aqueous solution of over the surface of the adhesive layer of one of the fragments of the self-adhesive polymer film opened as a result of implementing operation 2.1.

2.4. Placing the second of the fragments of the self-adhesive polymer film as a result of implementing operation 2.1 opened with the adhesive side on top of the layer of distributed particles of powdered activated

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charcoal impregnated with sodium chloride aqueous solution, on the fragment obtained as a result of implementing operation 2.3, so that the boundaries of these fragments coincide.

3. Formation of the third layer of the shield by cutting off a fragment from a roll of aluminum-containing foiled polymer film, the overall dimensions and shape of which are determined by the requirements for the overall dimensions and shape of the shield.

4. Fastening with spray adhesive to one of the surfaces of the second layer formed as a result of implementing operation 2, the first layer formed as a result of implementing operation 1, and to the other surface of the second layer, the third layer formed as a result of implementing operation 3.

The second of the technologies (hereinafter referred to as Technology 2) includes the following operations.

1. Forming the first layer of the shield.

1.1. Cutting off fragments from a roll of foiled polymer film taking into account the following conditions:

– the length of each fragment is equal to the length of the shield being manufactured;

– the width of each fragment is 10.0 cm.

1.2. Adhesive bonding of two opposite edges of a larger size on each of the fragments obtained as a result of implementing operation 1.1.

1.3. Cutting each of the elements obtained as a result of implementing operations 1.1, 1.2 with a step of 0.9 cm.

1.4. Cutting off a fragment from a roll of radio-transparent polymer film, the overall dimensions and shape of which are determined by the requirements for the overall dimensions and shape of the shield being manufactured.

1.5. Fastening sets of 3D elements with shape of the loop made of aluminum-containing foiled polymer film obtained as a result of implementing operations 1.3–1.4, on one of the surfaces of the fragment cut as a result of implementing operation 1.4.

2. Forming the second and third layers of the shield by alternately implementing operations 2 and 3, respectively, of the above-described Technology 1.

3. Implementing operation 4 of the above-described Technology 1.

The third of the technologies (hereinafter referred to as Technology 3) includes the following operations.

1. Forming the first layer of the shield.

1.1. Cutting identical fragments from a roll of aluminum-containing foiled polymer film to form 3D elements in the form of Mobius strips, taking into account the following conditions:

– the length of each film fragment is 5.0 cm;

– the width of each film fragment is 0.5 cm.

1.2. Forming 3D elements with shape of the Mobius strips from fragments of aluminum-containing foiled polymer film cut during the implementation of operation 1.1.

1.3. Cutting off a fragment from a roll of radio-transparent polymer film, the overall dimensions and shape of which are determined by the requirements for the overall dimensions and shape of the shield being manufactured.

1.4. Fastening, with a step of 1.0 cm, 3D elements with shape of the Mobius strips, formed during the implementation of operation 1, on one of the surfaces of the fragment cut during the implementation of operation 2, taking into account that the said elements must be located at an angle of 45° with respect to the surface of the said fragment.

2. Forming the second and third layers of the shield by alternately implementing operations 2 and 3, respectively, of the above-described Technology 1.

3. Implementation of operation 4 of the above-described Technology 1.

Thus, the first (surface) layer of the electromagnetic shields manufactured according to the Technology 1 contains the set of 3D-elements with shape of the Archimedes spiral (Fig. 1). The first (surface) layer of the electromagnetic shields manufactured according to the Technologies 2 and 3 contains the set of 3D-elements with shape of the loop and Mobius strip respectively (Figs. 2, 3).

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Fig. 1. Appearance of the 3D-element with shape of the Archimedes spiral

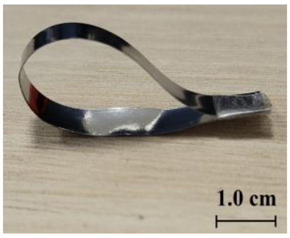

Fig. 2. Appearance of the 3D-element with shape of the loop

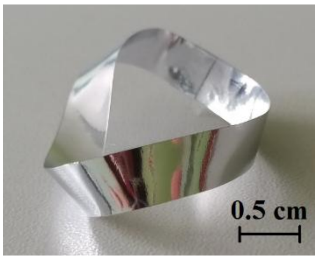

Fig. 3. Appearance of the 3D-element with shape of the Mobius strip

B. *The Research Methodology*

In course of the research the following was done:

1) 4 group of the electromagnetic shields experimental samples were manufactured according to the proposed technologies;

2) electromagnetic radiation reflection and transmission coefficients values in the frequency range 2.0–17.0 GHz (*R* and *T* respectively) of the manufactured samples were measured;

3) electromagnetic radiation absorption coefficient values in the frequency range 2.0–17.0 GHz (*A*) of the manufactured samples were calculated on the base of the measured *R* and *T*;

4) the comparative analysis of 2.0–17.0 GHz frequency responses of *A* values of the manufactured samples have been performed;

5) electromagnetic radiation reflection coefficient values in the infrared range (R_{IR}) have been obtained.

The characteristics of the manufactured electromagnetic shields experimental samples are presented in Table 1.

R and *T* values of the manufactured samples were measured with use of the panoramic meter of the reflection and transmission coefficients and two horn antennas according to the method presented in the paper [12]. *A* values of the manufactured samples were calculated according to the formulas presented in the marked paper.

TABLE I.
THE CHARACTERISTICS OF THE MANUFACTURED ELECTROMAGNETIC SHIELDS EXPERIMENTAL SAMPLES

Samples designation	**Technology used for the sample manufacturing**
Samples of the group 1	Technology 1 (only operations 2–4)
Samples of the group 2	Technology 1
Samples of the group 3	Technology 2
Samples of the group 4	Technology 3

R_{IR} values of the manufactured samples have been conducted in accordance with layout shown on Fig. 4.

The components used on the layout shown on Fig. 4 mean the following:

– dash-dotted line is the direction of electromagnetic radiation propagation from the source to object of measurement;

– object of measurement is one of the manufactured samples.

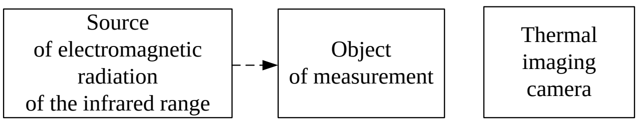

Fig. 4. Layout of the source of electromagnetic radiation of the infrared range, the object of measurement and the thermal imaging camera

R_{IR} values have been obtained according to the method including the following steps.

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1. Set up the source of electromagnetic radiation of the infrared range, the object of measurement and the thermal imaging camera in accordance with the layout shown on Fig. 4. The distance between the source of electromagnetic radiation of the infrared range and the object of measurement should be 100.0±10.0 mm. The distance between the object of measurement and the thermal imaging camera should be 200.0±20.0 mm.
2. Focus the thermal imaging camera lens on the central part of the object of measurement.
3. Turn on the source of electromagnetic radiation of the infrared range.
4. Use the thermal imaging camera to record the average value of the surface temperature of the object of measurement after 5.0 min from the moment of completion of the action within step 3.
5. Turn off the source of electromagnetic radiation of the infrared range.
6. Turn on the source of electromagnetic radiation of the infrared range after 30.0 min from the moment of completion of the action within step 5.
7. Repeat the actions within steps 3–6 at least four times.
8. Repeat the action within step 5.
9. Calculate the average value of the surface temperature of the object of measurement ($\bar{T}$) according to the formula:

$$\bar{T} = \frac{\sum_{i=1}^{n} T_{av_i}}{n}, \quad (1)$$

where n – the number of experiments conducted to record the average value of the surface temperature of the measurement object using the thermal imaging camera ($n \geq 5$); T_{av_i} – the average value of the surface temperature of the object of measurement recorded using a thermal imaging camera within the i-th experiment.

10. Install the source of electromagnetic radiation of the infrared range, the reference sample, R_{IR} value of which is ~ 98.0 %, and the thermal imaging camera in accordance with the layout shown in Fig. 4 (the specified reference sample must be installed instead of the measurement object).
11. Repeat actions within steps 2–9.
12. Install the source of electromagnetic radiation of the infrared range, the reference sample, R_{IR} values of which is ~ 2.0 %, and the thermal imaging camera in accordance with the layout shown in Fig. 4 (the specified reference sample must be installed instead of the measurement object).
13. Repeat actions within steps 2–9.
14. By comparing the results of calculating the average value of the surface temperature of the object of measurement obtained during the implementation of actions within steps 1–9, with the results of calculating the average value of the surface temperature of the reference sample, R_{IR} values of which is ~ 98.0%, obtained during the implementation of actions within steps 10, 11, and the results of calculating the average value of the surface temperature of the reference sample, R_{IR} values of which is ~ 2.0 %, obtained during the implementation of actions within steps 12, 13, establish the R_{IR} value of the object of measurement.

The conditions under which the measurements were carried out within steps 1–13 of the above-presented method were as follows:

– the surface temperature of the used source of electromagnetic radiation of the infrared range was 70.0±2.0 °C;
– the air temperature was 20.0±1.0 °C.

A heater based on an MR16 halogen lamp with a surface temperature of 70.0±2.0 °C was used as a source of electromagnetic radiation of the infrared range in course of R_{IR} values obtaining. A MobIR M4 thermal imaging camera (manufacturer – Wuhan Guide Infrared Ltd., People's Republic of China) was used as a thermal imaging camera in course of R_{IR} values obtaining, characterized by the following parameters:

– operating wavelength range – 8.0–14.0 μm;
– vertically and horizontally optical field of view – 25.0×19.0°;
– range of measured temperatures – from –25.0 to +250.0 °C;
– temperature measurement accuracy – ±2.0 °C;
– minimum observed area – 0.5 mm^2.

The body of the thermal imaging camera was placed at an angle of 90.0° relative to the surface of the measured sample.

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III. Results and Their Discussion

A. Characteristics of the Studied Samples

2.0–17.0 GHz frequency responses of *A* values of the samples of the manufactured electromagnetic shields experimental samples are presented in on Fig. 5.

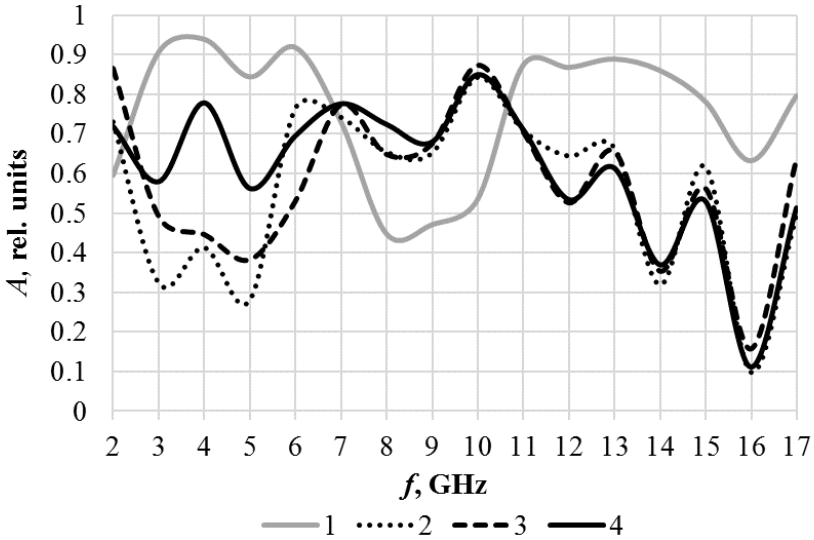

Fig. 5. 2.0–17.0 GHz frequency responses of A values of the samples of the groups 1, 2, 3 and 4 (curves 1, 2, 3 and 4 respectively)

As it can be seen from Fig. 4, *A* values in the frequency range of 7.0–10.5 GHz of the samples of the groups 2, 3 and 4 exceed by 0.05–0.35 rel. units *A* values in the specified frequency range of the samples of the group 1. This is due to the fact that *R* values in the frequency range of 7.0–10.5 GHz of the second of the above-mentioned samples exceed by 0.05–0.3 rel. units *R* values in the specified frequency range of the first of the above-mentioned samples (Fig. 6). This is because the 3D-elements consisting on the surfaces of the samples of the groups 2, 3 and 4 provide the dissipation of electromagnetic waves interacting with them [13].

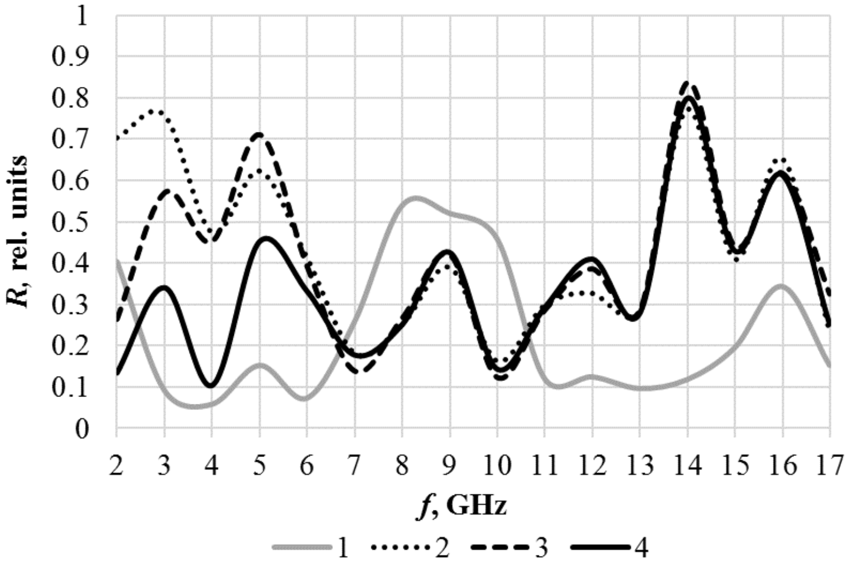

Fig. 6. 2.0–17.0 GHz frequency responses of R values of the samples of the groups 1, 2, 3 and 4 (curves 1, 2, 3 and 4 respectively)

According to the Fig. 5, we have concluded that effective absorption bandwidth the samples of the groups 2, 3 and 4 is greater on 0.5–6.0 GHz then effective absorption bandwidth the samples of the group 1 (Table 2).

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TABLE II.
MANUFACTURED ELECTROMAGNETIC SHIELDS EXPERIMENTAL SAMPLES CHARACTERISTICS

The shield brief description	Effective absorption band range	Effective absorption bandwidth, GHz
Double-layer electromagnetic shields based on activated charcoal impregnated with sodium chloride aqueous solution (i. e. electromagnetic shields manufactured according to the operations 2–4 of the Technology 1)	2.0–7.5 GHz; 10.0–17.0 GHz	5.5 7.0
Electromagnetic shields manufactured according to the Technology 1	2.0–2.5 GHz 5.5–13.5 GHz	0.5 8.0
Electromagnetic shields manufactured according to the Technology 2	2.0–3.0 GHz 6.0–13.5 GHz	1.0 7.5
Electromagnetic shields manufactured according to the Technology 3	2.0–13.5 GHz	11.5

Table 3 presents the obtained R_{IR} values of the manufactured electromagnetic shields experimental samples.

TABLE III. MANUFACTURED ELECTROMAGNETIC SHIELDS EXPERIMENTAL SAMPLES R_{IR} VALUES

Samples designation	$\bar{T}$, °C	R_{IR}, %
Samples of the group 1	38.0	42.0
Samples of the group 2	46.0	72.0
Samples of the group 3	49.0	86.0
Samples of the group 4	47.0	78.0
Reference sample, R_{IR} value of which is ~ 2.0%	28.0	2.0
Reference sample, R_{IR} value of which is ~ 98.0%	52.0	98.0

As it follows from the Table 3, R_{IR} value of the samples of group 1 lower on 30.0–44.0 % compared with R_{IR} values of the samples of groups 2, 3 and 4. This is because the average value of the surface temperature of the samples of group 1 lower on 8.0–11.0 °C compared with the average value of the surface temperature of the samples of groups 2, 3 and 4, when these samples are influenced during 5.0 min by electromagnetic radiation of the infrared range, the temperature of the source of which is 70.0±2.0 °C. This is because the surface layers of the samples of groups 2, 3 and 4 consists on the components made from the aluminum-containing foiled polymer material, providing the reflection of the most part of electromagnetic waves of infrared range interacting with it [14, 15].

IV. CONCLUSION

Thus, electromagnetic shields manufactured according to the proposed technologies are wideband ones. This is because the 3D-elements containing in their surface layers provide microwaves dissipating. These shields can be used for the development of the:

– partitions functional zoning of rooms (i.e. allocation of shielded zones in rooms) in which electronic devices are located that are sensitive to the effects of microwave and thermal interferences and / or are sources of microwave and infrared radiation.;

– modules intended for cladding the walls of shielded rooms in which electronic devices are located that are sensitive to the effects of microwave and thermal interferences and / or are sources of microwave and infrared radiation.

The indicated zones or rooms are used for conducting microwave measurements or testing and calibration equipment used for such measurements conducting [16]. Also such rooms or zones are necessary for location equipment used for realization of information technologies (personal computers, servers, wireless routers etc.) [17, 18].

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