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Microwave and infrared electromagnetic shields based on aluminum-containing polymer film

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ABSTRACT

The technology of development microwave and infrared electromagnetic shields based on double-layer metalized polymer film and synthetic non-woven fibrous material is proposed. This technology consists in heat pressing of the construction, which is two fragments of the said fibrous material, between which fragments of the said film are uniformly distributed. The characteristics of electromagnetic radiation absorption and reflection in the frequency range of 0.7–17.0 GHz of the shields samples of various types developed in correspondence with the proposed technology are presented. The sample of each type differed in the number of fragments of double-layer metalized polymer film included in their composition (namely, the ratio between the total area of surface areas covered with double-layer metalized polymer film fragments and the total area of surface areas not covered with such fragments). In addition, the results of assessing the change in temperature of the front and back surfaces of the shields samples of each type as a result of the impact of infrared electromagnetic radiation on the first of the said surfaces are presented. It was found that electromagnetic shields developed in correspondence with the proposed technology are multi-band electromagnetic radiation absorbers in the frequency range of 1.6–17.0 GHz, which is their key advantage over their analogues. Such shields could be used for selection in the rooms zones for standing equipment sensitive to the microwave and thermal noise.

KEYWORDS

absorption • aluminum-containing polymer film • electromagnetic shield • polyurethane matrix • infrared range microwave range • reflection

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Introduction

In order to create optimal conditions for the electronic devices functioning, it is required to protect them from the influences of electromagnetic radiation in both the microwave [1–5] and infrared [6–10] wavelength ranges. This is because that the influence of infrared electromagnetic radiation on electronic device components, as well as the influence of microwave electromagnetic radiation on them, lead to their premature failure. The following are prerequisites for premature failure of electronic device components due to influence of infrared electromagnetic radiation [11–15]: microscale deformation; changes of the volt–ampere characteristics parameters; changes of the electrical conductivity values.

To protect electronic devices components from the influence of microwave and infrared electromagnetic radiation, it is necessary to use microwave and infrared electromagnetic shields. The following types of such shields are currently known:

1. Textile material with a polyurethane coating, onto which a silver layer is applied using the magnetron sputtering method [16]. The electromagnetic radiation reflection coefficient value of this material in the microwave wavelength range is high value. The emissivity value of this material in the infrared wavelength range is low.
2. Hydrophilic PET fabric with a nanofiber coating based on PVA–co–PE, onto which a two–layer SiO2/Al film is applied using the magnetron sputtering method [17]. This fabric is characterized by high electrical conductivity and the presence of roughness. The size of this fabric roughness is comparable to the length of electromagnetic waves in the visible and infrared ranges.

The main disadvantage of shields [16,17] is their low manufacturability, which is caused by the following disadvantages of magnetron sputtering [18–20]: plasma instability; inability to achieve high–speed sputtering at low temperatures for strong magnetic materials due to magnetic flux limitations. In addition, of the electromagnetic radiation reflection coefficient values of these shields in the microwave wavelength range [16,17] are high. In this regard, these shields can be a source of passive electromagnetic interference in the specified wavelength range.

In connection with the above, the aim of the presented work was defined as the proposition and experimental confirmation of the technology for the development of microwave and infrared electromagnetic shields with the following properties in comparison with analogues: higher manufacturability; lower electromagnetic radiation reflection coefficient values in the microwave wavelength range (higher values of the electromagnetic radiation absorption coefficient in the specified wavelength range) [16,17]; developing the shields experimental samples developed in the correspondence with the proposed technology; assessment of the electromagnetic radiation absorption coefficient values in the microwave range of the developed shields samples; assessment of the change in the temperature of the front and back surfaces of the developed shields samples as a result of the impact on the first of the specified surfaces of infrared electromagnetic radiation.

Materials and Methods

The proposed technology includes the following operations:
1. Cutting out two same fragments of synthetic non–woven material. The dimensions and shape of such fragments are defined by the requirements to dimensions and shape of the electromagnetic shield being developed.
2. Cutting out fragments of double–layer metalized polymer film in correspondence with the following conditions: the fragments length and width should not exceed 3.0 and 1.0 cm, respectively; the fragments total area should be C % of the area of the fragments cut as a result of operation 1.
3. Uniform chaotic distribution of the double–layer metalized polymer fragments (operation 2), over the surface of one of the synthetic non–woven material fragments (operation 1).
4. Placing the other synthetic non–woven material fragment (operation 1) on top of the distributed double–layer metalized polymer fragments (operation 3).

5. Keeping the obtained construction in the heat press in correspondence with the following conditions: duration of 10.0 min; temperature of the heat press of ~ 250.0 °C.

Double–layer metalized polymer film was used like the main component for the developing shields in the correspondence with the proposed technology due to the following reasons [21–23]: high electrical conductivity; high infrared electromagnetic radiation reflection coefficient.

Four types of shields samples were manufactured for the study. The type 1 sample was the reference one. It was a fragment of double–layer metalized polymer film. The types 2, 3 and 4 samples were developed in the correspondence with the proposed technology. Each of the samples of the listed types differed in the *C* value (Table 1).

Table 1. Characteristics of manufactured shields samples of the types 2, 3 and 4

Sample	***C*, %**
Type 2 sample	50.0
Type 3 sample	65.0
Type 4 sample	75.0

The reference sample (the type 1 sample) was manufactured due to the following reasons:

1. to obtain the electromagnetic radiation absorption and transmission characteristics and surface temperature for the double–layer metalized polymer film, on the base of which the types 2, 3 and 4 samples were manufactured;
2. to define the difference between the electromagnetic radiation absorption and transmission characteristics and surface temperature of the double–layer metalized polymer film and the types 2, 3 and 4 samples manufactured on the base of this film (on the base of this difference it's possible to establish in what degree electromagnetic radiation absorption coefficients values of the types 2, 3 and 4 samples greater than electromagnetic radiation absorption coefficients values of the double–layer metalized polymer film, on the base of which these samples were manufactured).

To assess the electromagnetic radiation absorption coefficient values in the microwave range of the manufactured shields samples, the following was implemented.

1. The electromagnetic radiation reflection and transmission coefficients values by power (S11, dB and S21, dB respectively) in the frequency range 2.0–17.0 GHz were measured. The setup used in course of such measurements including the following components (Fig. 1): panoramic meter of transmission and reflection coefficients SNA 0.01–18; two horn antennas P6–23M with aperture size 351.0 × 265.0 mm^2 (type of the indicated antennas polarization is linear one). The measurements were carried out in correspondence with the method described in [24]. The measurements were carried out in the frequency range 0.7–17.0 GHz. This frequency range is associated with the operating frequencies of base stations of mobile communications, equipment used to build wireless information systems, radar stations, satellite systems, microwave ovens which together are sources of external electromagnetic fields for electronic devices [25–29].
2. The electromagnetic radiation reflection and transmission coefficients values (*R* and *T* respectively in relevance units (further – rel. units)) were calculated. The following equations are used in course of such calculations: $R = 10^{S_{11/10}}$, rel. units; $T = 10^{S_{21/10}}$, rel. units.

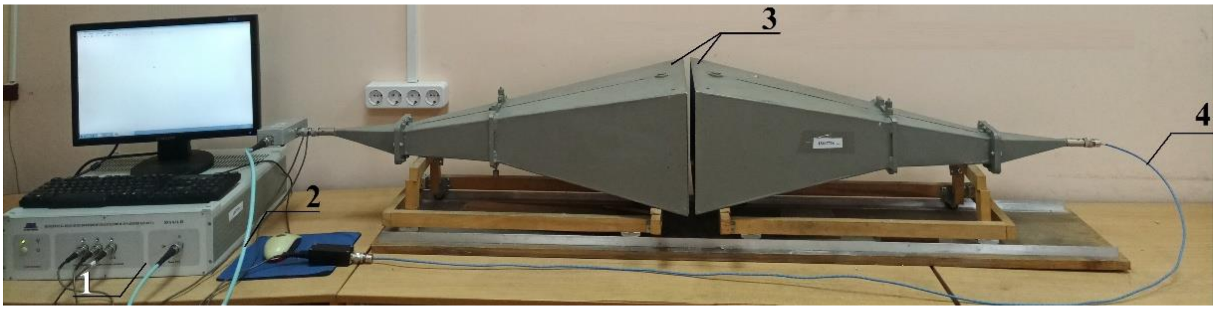


Fig. 1. Photo of the setup used in course of electromagnetic radiation reflection and transmission coefficients values measurements (1 – panoramic meter of transmission and reflection coefficients SNA 0.01–18; 2, 4 – coaxial waveguide; 3 – horn antennas P6–23M)

3. The electromagnetic radiation absorption coefficients values (*A*, rel. units) were calculated with use of the following equation: $A = 1 - R - T$, rel. units.

The technique presented in [30] was used to assess the change in the temperature of the front and back surfaces of the manufactured shields samples as a result of the impact of infrared electromagnetic radiation on the first of the specified surfaces. The conditions for performing the assessment were as follows: surface temperature of the used infrared electromagnetic radiation source of 70.0 ± 2.0 °C; duration of exposure of the sample to infrared electromagnetic radiation of 60.0 ± 1.0 min; air temperature of 20.0 ± 1.0 °C.

MobIR M4 thermal imaging camera, infrared electromagnetic radiation source based on MR16 halogen lamps, and C–01 electronic stopwatch were used during the assessment.

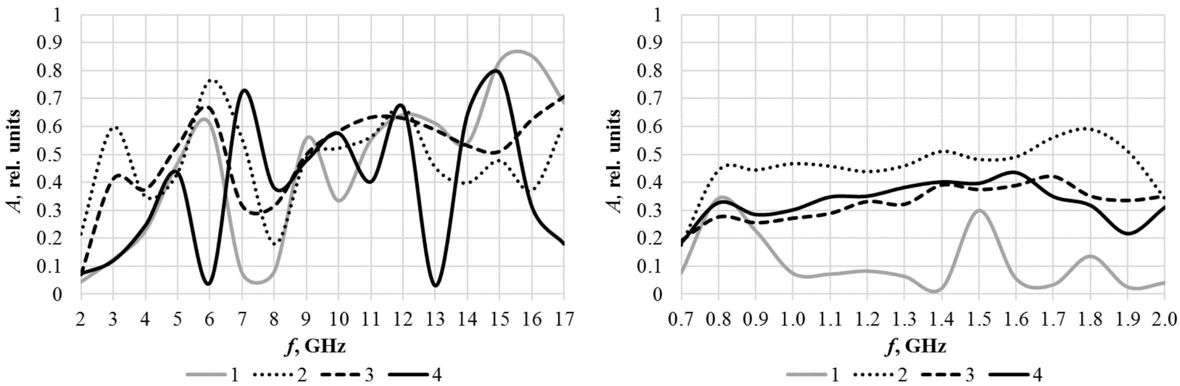
Results and Discussion

Results of measuring of S11 and S21 values of the types 1–4 samples on the base of which A values of these samples have been calculated are systematized in Table 2. *A* characteristic in the frequency range 0.7–17.0 GHz of the types 1–4 samples are presented on Fig. 2. As it can be seen from Fig. 2(a), *A* values in the frequency range 0.7–2.0 GHz of the electromagnetic shields samples developed in the correspondence with the proposed technology decrease from 0.2–0.6 to 0.2–0.45 rel. units, if the *C* value characteristic for these samples increases from 50.0 % till 65.0 or 75.0 %. This is because *R* values in the frequency range 0.7–2.0 GHz of such samples increase from 0.25–0.7 to 0.5–0.7 rel. units if the *C* value characteristic for these samples increases from 50.0 % till 65.0 or 75.0 % (Fig. 3(a)).

As can be seen from Fig. 2(b), if the *C* value characteristic for the samples of electromagnetic shields developed in the correspondence with the proposed technology increases from 50.0 till 65.0 % *A* values of such samples: decrease from 0.2–0.75 to 0.1–0.65 rel. units in the frequency range 2.0–7.5 GHz; increase from 0.2–0.6 to 0.3–0.7 rel. units in the frequency range 7.5–17.0 GHz. This explains *R* values of such samples under the specified condition increase from 0.1–0.7 to 0.25–0.85 rel. units in the frequency range 2.0–17.0 GHz (Fig. 3(b)); *T* values in the frequency range 7.5–17.0 GHz of the samples with $C = 50.0$ % is greater than *T* values in the specified frequency range of the samples with $C = 65.0$ %.

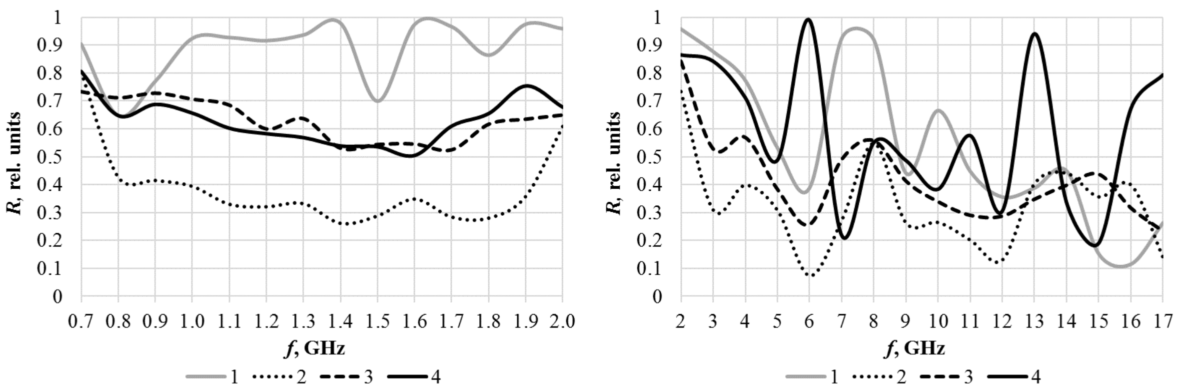
Table 2. Results of measuring of S_{11} and S_{21} values of the types 1–4 samples

Frequency, GHz	Type 1 sample		Type 2 sample		Type 3 sample		Type 4 sample	
	S_{11}, dB	S_{21}, dB	S_{11}, dB	S_{21}, dB	S_{11}, dB	S_{21}, dB	S_{11}, dB	S_{21}, dB
2.0	−0.2	−44.3	−1.4	−12.8	−0.7	−10.6	−4.7	−19.7
3.0	−0.6	−37.0	−5.1	−10.3	−2.8	−12.2	−0.7	−14.3
4.0	−1.1	−37.0	−4.0	−6.0	−2.4	−12.5	−1.5	−13.9
5.0	−2.7	−33.5	−5.1	−5.9	−4.2	−10.6	−3.1	−11.2
6.0	−4.1	−25.3	−11.3	−7.9	−5.9	−11.0	0.0	−12.8
7.0	−0.3	−29.1	−5.7	−7.6	−3.1	−7.2	−6.6	−12.4
8.0	−0.4	−28.8	−2.6	−5.6	−2.5	−9.0	−2.6	−11.7
9.0	−3.6	−27.0	−5.8	−6.0	−3.8	−10.5	−3.1	−14.6
10.0	−1.8	−28.5	−5.8	−6.7	−4.7	−11.0	−4.2	−14.0
11.0	−3.5	−28.9	−6.9	−6.3	−5.4	−11.0	−2.4	−16.8
12.0	−4.5	−25.2	−8.8	−7.0	−5.4	−10.7	−5.1	−16.0
13.0	−4.1	−27.2	−3.9	−8.4	−4.6	−11.8	−0.3	−15.6
14.0	−3.5	−19.6	−3.6	−7.9	−4.0	−11.4	−4.8	−17.2
15.0	−8.2	−18.2	−4.5	−7.8	−3.6	−12.8	−7.2	−17.3
16.0	−9.4	−14.7	−4.0	−6.4	−5.0	−12.2	−1.7	−18.4
17.0	−5.8	−12.7	−8.6	−6.1	−6.3	−12.1	−1.0	−15.9



(a) (b)

Fig. 2. Graphs of the dependence of *A* characteristic on the frequency range (a) 0.7–2.0 and (b) 2.0–17.0 GHz of the types 1–4 samples (curves 1–4 respectively)



(a) (b)

Fig. 3. Graphs of the dependence of *R* characteristic on the frequency range (a) 0.7–2.0 and (b) 2.0–17.0 GHz of the types 1–4 samples (curves 1–4 respectively)

As can be also seen from Fig. 2(b), if the *C* value characteristic for the electromagnetic shields samples developed in the correspondence with the proposed technology increases from 50.0 till 75.0 % *A* values of such samples: decrease from 0.2–0.75 to 0.1–0.6 rel. units in the frequency range 2.0–7.0 GHz and from 0.55–0.65 to 0.05–0.6 rel. units in the frequency range 10.5–13.5 GHz and from 0.4–0.6 to 0.2–0.4 rel. units in the frequency range 16.0–17.0 GHz; increase from 0.2–0.6 to 0.35–0.75 rel. units in the frequency range 7.0–10.5 GHz and from 0.4–0.5 to 0.4–0.8 rel. units in the frequency range 13.5–16.0 GHz. This is due to *R* values of such samples under the specified condition increase from 0.1–0.7 to 0.2–0.99 rel. units in the frequency range 2.0–17.0 GHz (Fig. 3(b)), and *T* values in the frequency ranges 7.0–10.5 and 13.5–16.0 GHz of the samples with *C* = 50.0 % is greater than *T* values in the specified frequency ranges of the samples with *C* = 75.0 %.

It also seen from Fig. 2, that *A* values of the electromagnetic shields samples developed in the correspondence with the proposed technology is greater on 0.1–0.6 rel. units then that *A* values of the sample in the form of the fragment of double–layer metalized polymer film. Oscillations in the *R* characteristics of the samples may be due to the antiphase interaction of electromagnetic waves reflected from the sample surfaces and electromagnetic waves incident on them. Furthermore, this may be due to the dependence of the electrical conductivity of the double–layer metalized polymer film, which is to be used to fabricate the proposed electromagnetic shields, on the frequency of the electromagnetic radiation. Table 3 presents the values of effective absorption bands and bandwidths of the studied samples. It follows from Table 2, that the type 3 sample has the widest effective absorption band compared with the 1, 2 and 4 type samples.

Table 3. The values of effective absorption band and bandwidth of the studied samples

Sample	Effective absorption band, GHz	Effective absorption bandwidth, GHz
Type 1 sample	5.0–16.5 8.7–9.2 10.5–17.0	1.5 0.5 6.5
Type 2 sample	1.6–1.9 2.5–3.5 5.0–7.0 9.0–12.8 16.5–17.0	0.3 1.0 2.0 3.8 0.5
Type 3 sample	4.5–6.5 9.0–17.0	2.0 8.0
Type 4 sample	6.5–7.8 9.0–10.5 11.5–12.5 13.5–15.5	1.3 1.5 1.0 2.0

Graphic dependencies obtained from the results of assessing the change in temperature of the front and back surfaces of the manufactured shields samples as a result of exposure of the first of the indicated surfaces to infrared electromagnetic radiation are presented on Fig. 4. It follows from Fig. 4 that as a result of the increase from 50.0 to 75.0 % of *C* value, typical for shields samples developed in the correspondence with the proposed technology: the temperature of their front surface increases from 45.0 ± 1.0 to 50.0 ± 1.0 °C under the conditions in which the studies were conducted; the temperature of their back surface decreases from 36.0 ± 1.0 °C to 34.0±1.0 °C under the conditions in which the studies were conducted. This is due to the increase in the value of the electromagnetic radiation reflection coefficient in the infrared wavelength range of the above–mentioned shields. It should be noted that the temperature of the front surface of the type 1 sample under the conditions in which the studies were conducted is 52.0 ± 1.0 °C.

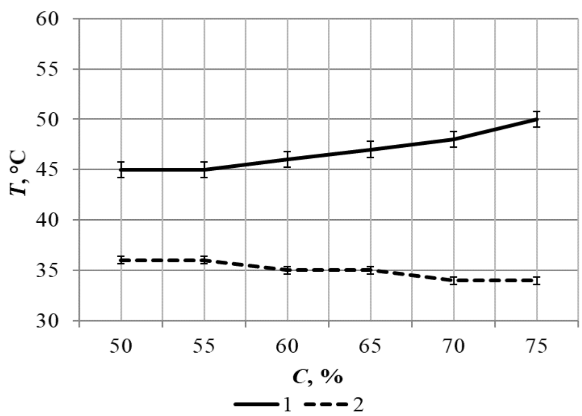


Fig. 4. Graphs of the dependence of the temperature of the front (curve 1) and back (curve 2) surfaces of the types 2–4 samples on the ratio *C*

Conclusions

Thus, electromagnetic shields developed in the correspondence with the proposed technology are multi–band absorbers of the electromagnetic radiation in the frequency range 1.6–17.0 GHz, which is one of their advantages compared to their analogues [16,17]. In addition, these shields, compared to their analogues [16,17], are more manufacturable. This is due to the fact that the time costs for their production are lower, and the degree of reproducibility of their manufacturing technology is higher.

Electromagnetic shields developed in correspondence with the proposed technology could be used for selection in the rooms zones for standing equipment sensitive to the microwave and thermal noises. In such cases they look like screens that must be attached to the frame made from radio transparency material.

CRediT authorship contribution statement

Olga V. Boiprav : writing – original draft, writing – review & editing; **Natalia V. Bogush** : investigation, validation; **Vadim V. Lobunov** : methodology, investigation; **Vladimir V. Soloviev** : formal analysis.

Conflict of interest

The authors declare that they have no conflict of interest.

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