LIGHTWEIGHT MICROWAVE ABSORBERS WITH LOOP-LIKE SURFACE IRREGULARITIES BASED ON FOILED MATERIALS FOR ANECHOIC CHAMBERS

ABSORBENTES DE MICROONDAS LIGEROS CON IRREGULARIDADES SUPERFICIALES EN FORMA DE BUCLE A BASE DE MATERIALES LAMINADOS PARA CÁMARAS ANECOICAS

Olga V. Boiprav*, **Vadim A. Bogush**

Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus.

(Received: jul./2023. Accepted: feb./2024)

Abstract

The paper presents new technique of foil-containing microwave absorbers manufacturing. These absorbers surface is characterized by the periodic structure and contain loop-like irregularities made from foiled polymer material. Electromagnetic radiation absorption characteristics in the frequency range 0.7–17.0 GHz of the experimental samples of the absorbers manufactured in accordance to the presented technique are described in the paper. These characteristics were obtained to experimentally justify the presented technique. The amplitude of the described characteristics changes from 0.5 to 0.95 in frequency ranges 0.7–2.0 GHz, 4.0–16.0 GHz. It means that the absorbers, manufactured in accordance to the presented technique are wide-band. Moreover, these absorbers are characterized by lower weight compared to the analogs. They are prospective for use for development of movable partitions for anechoic chambers.

Keywords: absorption coefficient, electromagnetic radiation, foiled material, microwave absorber.

* smu@bsuir.by

doi: https://doi.org./10.15446/mo.n69.110073

Resumen

El documento presenta una nueva técnica de fabricación de absorbentes de microondas que contienen láminas. La superficie de estos absorbentes se caracteriza por la estructura periódica y contiene irregularidades en forma de bucle hechas de material polimérico laminado. En el artículo se describen las características de absorción de radiación electromagnética en el rango de frecuencia de 0.7–17.0 GHz de las muestras experimentales de los absorbentes fabricados de acuerdo con la técnica presentada. Estas características se obtuvieron para justificar experimentalmente la técnica presentada. La amplitud de las características descritas cambia de 0.5 a 0.95 en rangos de frecuencia de 0.7–20 GHz, 4.0–16.0 GHz. Esto significa que los absorbentes, fabricados de acuerdo con la técnica presentada, son de banda ancha. Además, estos absorbentes se caracterizan por un menor peso en comparación con los análogos. Su uso está previsto para el desarrollo de tabiques móviles para cámaras anecoicas.

Palabras clave: coeficiente de absorción, radiación electromagnética, material laminado, absorbente de microondas.

Introduction

One type of modern microwave absorbers is those with surfaces characterized by irregularities. These irregularities provide the dissipation of electromagnetic radiation, interacting with them. Due to such feature, these absorbers are characterized by the following advantages [1]:

- Wide operating frequency band;
- Good matching of surface impedance with air impedance.

As a rule, the considered absorbers are made on the base of electrically conductive materials (carbon containing or metal containing powders or fibers) [1–5]. They are widely used for anechoic chambers and shielded rooms building. The panels for covering the walls of such chambers and rooms and the movable inside partitions for the latter are manufactured on the base of the considered absorbers. To simplify the installation and use of the latter, the low mass per square unit should be provided for them.

The research, conducted in the course of the current article preparation, has been targeted to experimentally justify a new technique for obtaining lightweight microwave absorbers, the surface of which is characterized by a set of irregularities.

In the course of this research, the following objectives have been solved:

1. The experimental samples of the absorbers have been manufactured in accordance with the new technique;
2. Electromagnetic radiation absorption coefficients values in the frequency range 0.7–17.0 GHz of the manufactured experimental samples have been calculated;
3. Patterns of change of electromagnetic radiation absorption coefficients values of the absorbers, manufactured in accordance with the new technique, have been established depending on the width of irregularities contained on these absorbers surface.

Materials and Methods

The proposed technique is new compared to analogs for the following reasons:

1. It is based on the use $50 \mu m$ foiled polymer material. This material, compared to carbon-containing or metal-containing powdered materials or fibers, offers several advantages:

    a) Lower cost;

    b) The manufacturing process of electromagnetic radiation absorbers based on this material does not produce dust, which could affect nearby radioelectronic equipment, where this process is realized.

2. Its essence is to form loop-like surface irregularities on the base of the indicated material. Such irregularities are

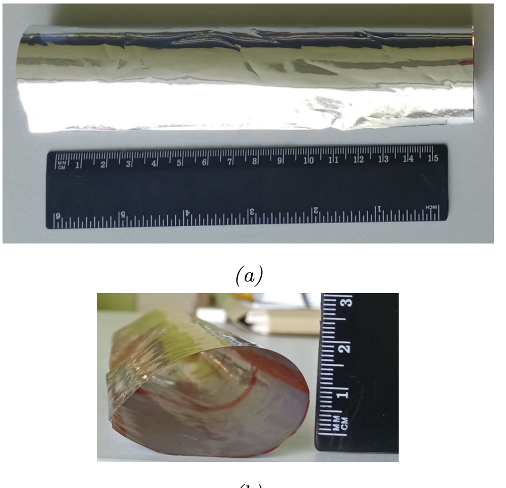
the analogs of loop antennas and could be considered like the volume electromagnetic resonators. Nowadays, only techniques for obtaining narrowband electromagnetic radiation absorbers on the base of plain loop resonators are known [6–8].

The proposed new technique contains the following stages.

Stage 1. Cutting of fragments from a roll of foiled polymer material. These fragments should be characterized by the following parameters:

- The length is equal to the width of the manufactured absorber;
- The width is not lower than the electromagnetic wave length at the middle frequency of the operating frequency range of the manufactured absorber (this requirement is due to the requirement for the perimeter length of the loop antenna [9]).

Stage 2. Adhesive connection of two opposite edges of a larger size for each of the fragments obtained on the stage 1 (Figure 1).



(a)

(b)

FIGURA 1. *Top (a) and side (b) view of the element, resulting from stage 2 implementation.*

Stage 3. Incision of each of the elements obtained on the stage 2, using a paper shredder (Figure 2). The spacing of the notches should be at least 0.05 of the electromagnetic wavelength at the middle frequency of the operating frequency range of the manufactured absorber (this condition must be taken into account in order to minimize the degree of dependence of the absorber absorption coefficient on the angle of incidence and the degree of polarization of the electromagnetic radiation interacting with it [10]).

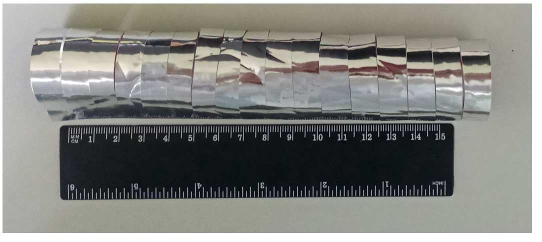


FIGURA 2. *Top view of the element obtained as a result of stage 3 implementation.*

Stage 4. Fixing the elements obtained on the stage 3 on a cellulose or polymer substrate.

In the course of solving the first task set to achieve the study aim, three types of electromagnetic radiation absorbers experimental samples were made in accordance with the proposed technique. The spacing of the notches on the elements used for the manufacture of experimental samples of type 1 was 0.3 cm. The spacing of the notches on the elements used for the manufacture of experimental samples of types 2 and 3 was 0.6 and 0.9 cm, respectively. In other words, the width of each of the loop-like irregularities of the manufactured experimental samples surface of types 1, 2 and 3 was 0.3 cm, 0.6 and 0.9 cm, respectively.

The top view of the manufactured experimental samples is shown in Figures 3-5.

In the course of solving the second task set to achieve the study aim, the following was done:

1. Measurements of electromagnetic radiation reflection ($S_{11}(f)$, in dB) and transmission ($S_{21}(f)$, in dB) coefficients values

Figura 3. *Top view of the experimental samples of type 1*

Figura 4. *Top view of the experimental samples of type 2*

Figura 5. *Top view of the experimental samples of type 3*

were performed in the frequency 0.7–17.0 GHz. This range was chosen due to the wide spread of the devices, which transmit signals on the frequencies belonging to this range [11–14].

2. To perform measurements, the equipment, including scalar network analyzer, horn-type antennas and coaxial waveguide, was used.

Connection diagrams of the listed equipment devices for $S_{11}(f)$ and $S_{21}(f)$ measurements are presented in Figure 6.

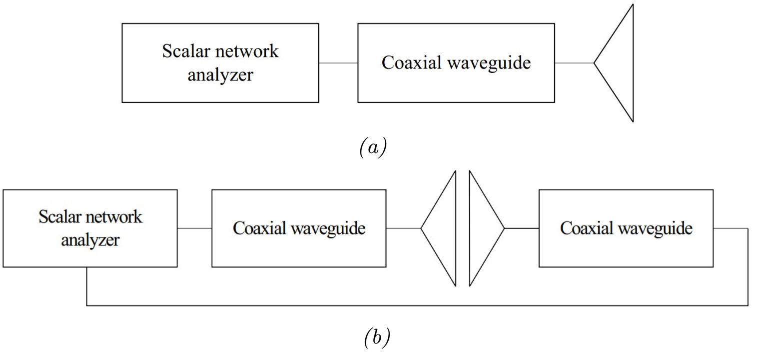


FIGURA 6. *Connection diagrams of equipment devices for $S_{11}(f)$ measurements (a) and $S_{21}(f)$ measurements (b)*

The process of $S_{11}(f)$ measurements and evaluation included the following stages:

Stage 1. Placing a metal plate near the transmitting antenna and performing the equipment calibration.

Stage 2. Placing the experimental sample near the transmitting antenna instead of the metal plate.

Stage 3. Registering $S_{11}(f)$.

Stage 4. Repeating stages 1–3 at least four times.

Stage 5. Calculation of the average value of the measurement results, obtained in stages 1–4 ($S_{11\mathrm{avg}}(f)$).

The process of $S_{21}(f)$ measurements and evaluation included the following stages:

Stage 1. Placing transmitting and receiving antennas opposite each other and performing the equipment calibration.

Stage 2. Placing the experimental sample between the transmitting and receiving antennas.

Stage 3. Registering $S_{21}(f)$.

Stage 4. Repeating stages 1–3 at least four times.

Stage 5. Calculation of the average value of the measurement results, obtained in stages 1–4 ($S_{21\text{avg}}(f)$).

Based on the results of $S_{11\text{avg}}(f)$ and $S_{21\text{avg}}(f)$ calculations, electromagnetic radiation absorption coefficient values ($A_{\text{av}}(f)$) in the frequency range 0.7–17.0 GHz were calculated in accordance with the following formulas [15]:

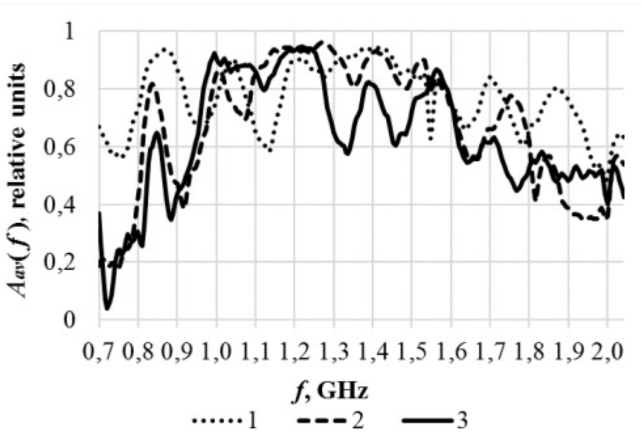
$$R(f) = 10^{\left(\frac{S_{11\text{av}}(f)}{10}\right)}, \text{ relative units}$$
$$T(f) = 10^{\left(\frac{S_{21\text{av}}(f)}{10}\right)}, \text{ relative units}$$
$$A_{\text{av}}(f) = 1 - R(f) - T(f), \text{ relative units}$$

where $R(f)$ is the electromagnetic radiation reflection coefficient value in relative units and $T(f)$ is the electromagnetic radiation transmission coefficient value in relative units.

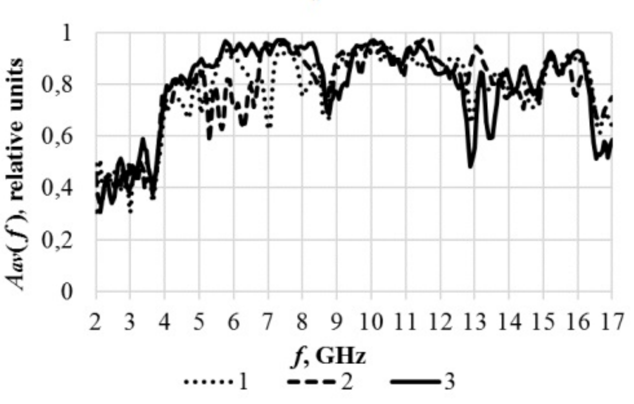
Results and Discussion

In the course of solving the third task set to achieve the study aim the following frequency dependences of $A_{\text{av}}(f)$ in the range 0.7–17.0 GHz have been obtained. These dependences are presented in Figure 7.

It follows from Figure 7(a) that electromagnetic radiation absorption coefficient values in frequency range 0.7–2.0 GHz of the experimental sample of type 1 change from 0.1 to 0.95.



(a)



(b)

FIGURA 7. *Frequency dependences of Aav(f) in the range 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of the experimental samples of types 1 (curves 1), 2 (curves 2) and 3 (curves 3)*

Electromagnetic radiation absorption coefficient values in the indicated range of the experimental samples of types 2 and 3 change from 0.2 to 0.95. Experimental sample of type 3 is characterized by lower values of electromagnetic radiation absorption coefficient in frequency range 0.7–2.0 GHz compared with experimental samples of types 1 and 2 due to the set of following reasons:

1. The square of the surface of loop-like irregularities of the experimental sample of type 3 is greater than the square of

the surfaces of loop-like irregularities of experimental samples of types 1 and 2.

2. Due to reason 1, the energy of electromagnetic waves reflected from the loop-like irregularities of the experimental sample of type 3 is greater than the energy of electromagnetic waves reflected from the loop-like irregularities of experimental samples of types and 2.

It is necessary to add that experimental sample of type 3 provide the decreased electromagnetic radiation transmission losses in frequency range 0.7–2.0 GHz compared with experimental samples of types 2 and 3. This is due to the following reasons:

1. The equivalent electrical circuit of the cells of considered experimental samples looks like scheme presented in Figure 8. Cell of every considered experimental sample is one row of loop-like irregularities. L-element in the presented scheme is equivalent of the set of loops. R-element in the presented scheme is equivalent of bottom part of the row of loop-like irregularities (see Figure 2). C-element in the presented scheme is equivalent of the gap between the neighbor rows of loop-like irregularities.

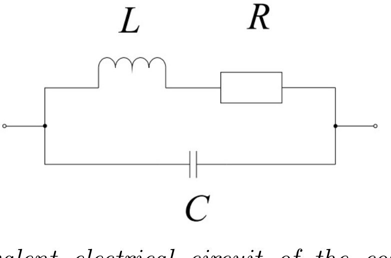


FIGURA 8. *The equivalent electrical circuit of the considered experimental samples*

2. $S_{21}(f)$ of the equivalent electrical circuit presented in Figure 8 is calculated by the following way [16].

$$S_{21}(f) = -\frac{2}{\sqrt{|Y(f)^2 + 4|}},$$

where $Y(f)$ is the normalized conductivity, calculated in accordance with the following formulas:

$$Y = \frac{1}{jX_L(f) - jX_C(f)'},$$
$$X_L(f) = 2\pi f L, \text{Ohm},$$
$$X_C(f) = \frac{1}{2\pi f C}, \text{Ohm}$$

where $X_L(f)$ and $X_C(f)$ are the reactance of the L-element and C-element, respectively;

L is the value of L-element inductance; C is the value of C-element capacitance.

$$L = \frac{D^2 \cdot n^2}{45D + 100l}, \mu\text{H},$$

where D is the L-element diameter, cm; l is the L-element length, cm; n is the number of loops.

3. As shown by the formulas presented in point 2, $S_{21}(f)$ of the equivalent electrical circuit containing the L-element is increased if the number of loops in such element is decreased.

   Electromagnetic radiation transmission losses in this case decreased because the value of these losses is inversely proportional to $S_{21}(f)$. In other words, decreasing the number of loop-like irregularities of the absorbers manufactured in accordance with the presented technique (i.e., increasing the width of these irregularities) leads to the decreasing of electromagnetic radiation transmission losses provided by these absorbers.

   It follows from Figure 7 (b) that electromagnetic radiation absorption coefficient values in frequency range 2.0–17.0 GHz of the considered experimental samples changes from 0.4 to 0.98. Experimental sample of type 3 is characterized by higher electromagnetic radiation absorption coefficient values in frequency range 4.0–8.0 GHz. This could be related to the set of the following reasons:

1. Total energy of electromagnetic waves dissipated by the loop-like irregularities of experimental samples of types 1 and 2 is higher than the total energy of electromagnetic waves dissipated by the loop-like irregularities of the experimental sample of type 3.

2. Electromagnetic radiation reflection coefficient values of experimental samples of types 1 and 2 increase in the frequency range of 4.0–8.0 GHz compared to the experimental sample of type 3. This is due to the effect of superposition of electromagnetic waves dissipated by the loop-like irregularities of experimental samples of types 1 and 2. These waves, resulting from the superposition, could impact the waves reflected by the surfaces of loop-like irregularities of experimental samples of types 1 and 2.

In general, the considered experimental samples provide absorption of electromagnetic radiation interacting with them due to the mechanism of electromagnetic waves multiply re-reflection that occurs when these waves distribute inside and between loop-like irregularities (waves multiply re-reflect from the inside surfaces of the irregularities and between them – see Figure 9). This mechanism appears due to the big difference between wave resistance of the air, which is inside the loop-like irregularities, and the foiled polymer material on the base of which these irregularities are formed.

Electromagnetic radiation absorption coefficient values in the frequency ranges of 2.0–4.0 GHz and 8.0–17.0 GHz of the considered experimental samples do not significantly depend on the width of the loop-like irregularities on their surfaces. This may be because, in this frequency range, the energy of electromagnetic waves reflected from the surfaces of the loop-like irregularities of the considered samples depends more on the diameter of these loops (i.e., the height of the irregularities) than on their width. This hypothesis is planned to be checked experimentally as part of future research.

Table 1 presents the summarized characteristics of effective absorption bands of the considered experimental samples.

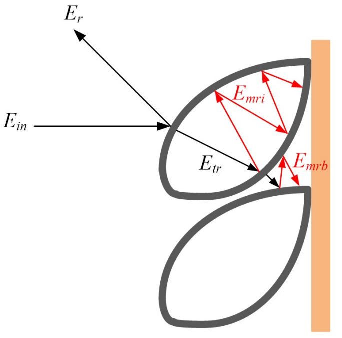


FIGURA 9. *Schematic illustration of electromagnetic wave interaction with the considered experimental samples (E_{in} – incident wave; E_r – reflected wave; E_{tr} – transmitted wave; E_{mri} – waves multiply re-reflected from the inside surfaces of the irregularities; E_{mrb} – waves multiply re-reflected between irregularities)*

Experimental sample name	Effective absorption band, GHz	Effective absorption band width, GHz	Average value of Aav (f) in effective absorption band, dB
Experimental sample of type 1	0.7–2.0; 4.0–16.0	1.3; 12.0	0.77; 0.83
Experimental sample of type 2	0.95–2.0; 4.0–16.0	1.05; 12.0	0.73; 0.84
Experimental sample of type 3			0.69; 0.85

TABLA 1. *Characteristics of the effective absorption bands of the considered experimental sample.*

It follows from Table 1 that absorbers manufactured according to the presented technique, characterized by surface loop-like irregularities with a width of 0.3 cm, have a wider effective absorption band in the frequency range of 0.7–2.0 GHz compared to the absorbers characterized by surface loop-like irregularities with widths of 0.6 cm and 0.9 cm. Moreover, average value of electromagnetic radiation absorption coefficient in the band 0.7–2.0 GHz of the first one is higher than average value of electromagnetic radiation absorption coefficient in the band 0.95–2.0 GHz of the second ones. All absorbers manufactured in accordance with the presented technique are characterized by the similar width of effective absorption band in the frequency range of 2.0–17.0 GHz. The average value of the electromagnetic radiation absorption coefficient in the band 4.0–16.0 GHz of the absorbers characterized by surface loop-like irregularities with a width of 0.9 cm is higher than the average value of the electromagnetic radiation absorption coefficient in the band 4.0–16.0 GHz of the absorbers characterized by surface loop-like irregularities with widths of 0.3 cm or 0.6 cm.

Conclusions

The recommendations for the practical use of the proposed technique are as follows (assuming the length of loop-like irregularities on the surface of the absorbers manufactured according to this technique is 10.0 cm):

1. The absorbers manufactured in accordance with the proposed technique, characterized by a 0.3 cm width of surface loop-like irregularities, are effective in the L-band.
2. The absorbers, manufactured in accordance with the proposed technique, characterized by a 0.9 cm width of the surface loop-like irregularities, are effective in C-, X- and Ku-bands.

As a result, the indicated absorbers could be used for creating the anechoic chambers, where radio measurements in marked bands are carried out. In general, the absorbers, manufactured in accordance with the proposed technique and characterized by a 10.0 cm length of surface loop-like irregularities, are not suitable for use for absorption electromagnetic radiation in S band.

Future research will be targeted to:

1. Check the hypothesis, put forward in course of substantiation of obtained patterns of change of electromagnetic radiation absorption coefficients values in the frequency in frequency ranges 2.0–4.0 GHz and 8.0–17.0 GHz of the absorbers, manufactured in accordance to the proposed technique (see section “Materials and Methods”);
2. Define the length, which should be provided for loop-like irregularities of surface of the absorbers manufactured

in accordance to the proposed technique, to make these absorbers suitable for use for absorption electromagnetic radiation in S band.

The absorbers manufactured in accordance to the proposed technique are prospective for use for development of movable partitions for anechoic chambers due to their low weight and cost.

References

[1] I. Catalkaya and S. Kent, The Applied Computational Electromagnetics Society Journal (ACES) **32**, 621–627 (2021).

[2] S. Xie, Y. Zhang, and et al., J. Mater. Sci.: Mater. Electron. **32**, 9208 (2021).

[3] Yohandri and Z. Affandi, J. Phys.: Conf. Ser. **1116**, 032043 (2018).

[4] A. Awasthi, A. Jaiswal, and R. Dayal, IRJET **5**, 835 (2018).

[5] R. Kubacki, W. Głuszewski, and et al., Int. J. Microw. Wirel. Technol. **10**, 754 (2018).

[6] S. Wang, G. Deng, A. Horestani, and C. Fumeaux, Electron Lett **52**, 812 (2016).

[7] K.P. Kaur, T.K. Upadhyaya, and M. Palandoken, PIER C **77**, 91 (2017).

[8] S. Genikala, A. Ghosh, and B. Roy, AEU - Int J Electron Commun **164**, 154629 (2023).

[9] J.S. Husayn and A.A.A. Al-Husayn, J Eng Sci U Babylon **21**, 987 (2013).

[10] A. Singh and C. Singh, International Journal of Computer Communication and informatics **3**, 1 (2021).

[11] N.A. Sukri, Z. Faiza, and et al., *A Tri-band Antenna for Satellite Applications at C, X and Ku Bands* (2021 IEEE Symposium on Wireless Technology and Applications, 2021) pp. 11–15.

[12] R. Wang, J.-J. Ma, and et al., IEEE Access **8**, 48557 (2020).

[13] S. Bogning, F. Frappart, and et al., Adv Space Res **68**, 672 (2021).

[14] M. Hasanov and N. Atayev, Problems of Information Technology **13**, 61 (2022).

[15] S. Geetha, K. Satheesh Kumar, and et al., J Appl Polym Sci **112**, 2073 (2009).

[16] I.Yu. Danilchev, Polytechnic Youth Journal **5** (2021).