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Original Research Article

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RADIO-ABSORBING MATERIALS BASED ON GRAPHITE PARTICLES IN EPOXY RESIN

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Abstract. *This paper presents the results of a study on radio-absorbing materials in the ultra-high frequency range of 78-118 GHz. Crystalline graphite powder (particle size 0.1 mm) was considered as the main radio-absorbing material. Epoxy resin was used as a substrate and a binder. The samples were prepared by dispersing the graphite powder across the surface of the epoxy resin substrate. The most effective working thickness of epoxy resin has been established experimentally. The geometric dimensions of the arrangement of the installation components at which the most effective signal recording is observed are calculated. The results of the studies showed that a film consisting of graphite particles on the surface of epoxy resin effectively shields radio emissions in the 3-millimeter range.*

Keywords: Radio-absorbing materials, radio frequency range, electromagnetic wave absorption, graphite, attenuator, radio-frequency generator, calorimeter, horn antenna.

1. Introduction

The development of modern radio-electronic technology, especially in the field of ultra-high frequencies (microwave), has led to a global problem of electromagnetic pollution, which can have a negative impact on the operation of radio equipment. The number of different sources of electromagnetic radiation (EMR) is increasing, and the frequency range used is expanding. All this requires addressing issues related to protection from EMI across a wide frequency range [1].

Radio-absorbing materials (RAM), capable of absorbing or attenuating radio wave radiation, are one of the effective means of solving these problems [2]. Such materials include ferrites [2], metal alloys [3], graphite [4], carbon nanotubes [5] and others. Thus, the material can be manufactured using components capable of absorbing or reflecting radio waves. This work aims to develop and study radio materials that effectively absorb EMR in the range of 78 – 118 GHz. The radio materials being developed must satisfy the ratio of "high protection efficiency – low manufacturing costs."

The object of study is graphite particles embedded in the matrix of the binder material. The choice of the object of study is due to the presence of a large number of works devoted to the study of radiophysical parameters of graphite, the prospects of using graphite particles as fillers in the materials under study. In particular, the next stage of research will be devoted to the production of polymer films with fillers from graphite particles of different sizes.

ED-20 epoxy resin was used as the binder. Epoxy resin easily adheres to surfaces requiring emitted electromagnetic interference (EMI) protection and is resistant to various pressures applied to the surface [6]. However, the authors do not consider issues related to the thickness of the epoxy resin. Graphite particles were pre-mixed in a certain proportion in an epoxy resin solution. The film samples under study were obtained by applying a mixture of various volumes (5 ml, 10 ml, and 15 ml) onto glass substrates (9.5x6 cm), transparent in the radio range under consideration.

The determination of the film thickness was carried out by transforming the formula for calculating the volume ($V = abc$, $c = V/ab$), where V is the volume, a is the width, b is the length, and c = h is the thickness of the epoxy resin. The obtained sample thickness values for epoxy resin of various volumes: at V=5 ml, $h_1 = 0.8\ mm$; at V=10 ml, $h_2 = 1.7\ mm$; at V=15 ml, $h_3 = 2.6\ mm$.

2. Material and Methods

The experimental setup consists of a G4-183M signal generator, an AP-20 attenuator, two rectangular horn antennas, and an M1-25 M/03 calorimetric power meter. At the initial stage, work was carried out to determine the optimal relationship between the geometric parameters and frequency characteristics of the experimental setup. When studying the characteristics of radio-absorbing materials, it is necessary to first create conditions that provide the ability to perform various actions to increase the measuring capabilities of the device. For example, to ensure a change in the angle of incidence of the EMR, a change in the frequency of the generator, and the polarization of the electromagnetic wave entering the absorbing layer (material under study). To do this, the first few stages of measurements must be carried out in “empty space”, without objects of study.

An experimental setup was assembled in accordance with the aforementioned requirements. To maintain the stability of the instruments and their position at the same level, the generator and calorimeter were installed on special metal bases. A Standa rotary platform was used to rotate the test sample. The structural diagram of the experimental setup is shown in Figure 1.

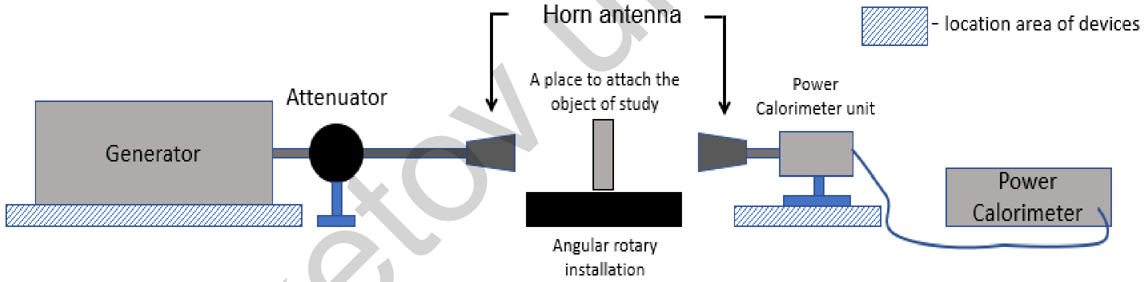


Fig.1. Structural diagram of the experimental setup

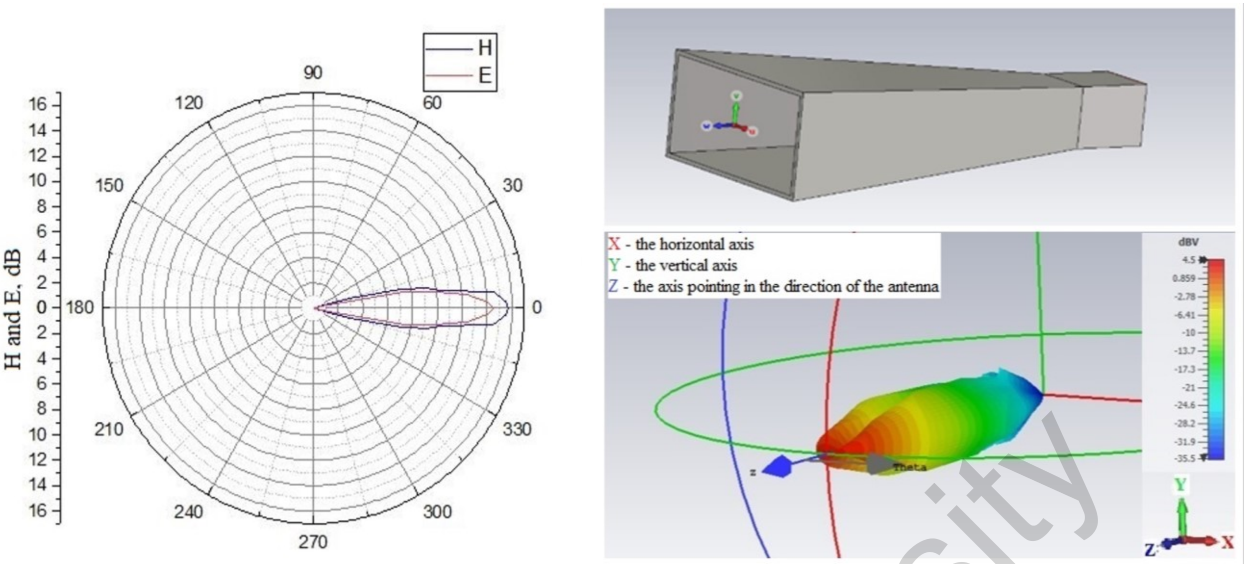
In the assembled installation, the angle between the transmitting and receiving horn antennas is small. Therefore, we first determined the radiation pattern of the horn antenna [7, 8]. The studies were carried out at a frequency of 98 GHz. The attenuation level (attenuator) of the original EMR was set to 5 dB. The rotation step of the receiving antenna corresponded to 3-5°.

The results of measurements in the E and H planes, obtained by changing the angle of the receiving antenna, are presented in Table 1.

Table 1. Results of measuring a horn antenna in the E and H planes

Angle		0°	5°	8°	10°	13°	15°	16°	20°
Signal power, dB	E	14.47	12.43	9.54	7.53	1	0	0	0
	H	15.71	14.59	10.21	9.21	6.98	3.01	1	0

The obtained values made it possible to construct a radiation pattern, as well as a 3D model of the antenna and diagram (Figure 2). All charts and graphs presented in the work were constructed using the OriginPro program and the Ansys HFSS environment. Based on the results obtained, the distances corresponding to the effective placement of equipment components were calculated depending on the size of the sample under study. The calculation results are presented in Table 2.



a) b)

Fig.2. Antenna radiation pattern in E and H planes (a), 3D antenna models and radiation patterns (b)

Table 2. Effective distance depending on the width and height of the object under study

Height, cm Width, cm	4	5	6	7	8	9	10
4	4.66	6.82	8.99	11.15	13.32	15.48	17.65
5	4.71	6.82	8.99	11.15	13.32	15.48	17.65
6	6.46	6.82	8.99	11.15	13.32	15.48	17.65
7	8.20	8.20	8.99	11.15	13.32	15.48	17.65
8	9.95	9.95	9.95	11.15	13.32	15.48	17.65
	Effective distance, cm						

The results presented in Table 2 show the dependence of the distance between the antennas and the sample on the size of the sample itself. Changing the size of one of the sides of the object under study is accompanied by a mandatory adjustment of the distance between the sample and the antenna. This is necessary in order to cover the entire EMR propagation area and eliminate errors in the registration of the useful signal. Based on these results. a block diagram (Figure 3) of the location of the sample relative to the antennas was constructed. Subsequently, the installation was assembled according to this diagram.

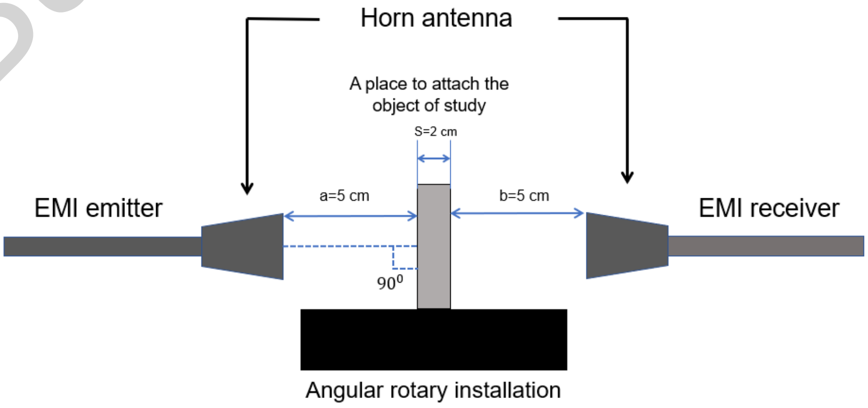


Fig.3. Structural diagram of the sample arrangement relative to the antennas

The distance between the horn antennas and the object was set in strict accordance with the calculation using a caliper. The assembled experimental setup allows for consistent measurements of both transmission and reflection coefficients. This is achieved by using an automated rotating platform (Standa) and a sample holder design. If it is necessary to change the nature of the experimental work, the overall design of the setup is not violated. Accordingly, there is no need for additional work on setting up the devices. The measured data from the recording part can be automatically transferred to a personal computer. Where, subsequently, they can be processed and saved in Excel format. Thus, at this stage, the work on constructing and assembling the experimental installation was completed. The radiation pattern was determined and the geometric position of the installation components relative to each other was calculated.

3. Experimental results and discussion

To establish a safe operating mode of the equipment, the "empty space" measurements were preliminarily carried out at different levels of signal attenuation. The level of attenuation of the power of the initial EMI was set to 25 dB. Then, the attenuator was sequentially opened with a step of 5 dB and the readings were taken from the display of the calorimetric meter. Registration of absorption coefficients was carried out at fixed frequencies of 78.5 GHz, 98 GHz and 118 GHz. Based on the measurement results, a graph of the dependence of the transmitted signal on the frequency and attenuation level of the initial EMI was constructed. The results were processed and presented in 3D format in Figure 4,a. We observe that the level of the emitted signal at the extreme frequencies is lower than the level at 98 GHz. This observed change in signal power is associated with the technical characteristics of the experimental equipment. It was also determined that an EMI attenuation level of 5 dB is the most optimal, as it allows measurements to be conducted without compromising the accuracy of results or the equipment's integrity. Subsequent measurements were conducted at this attenuation level.

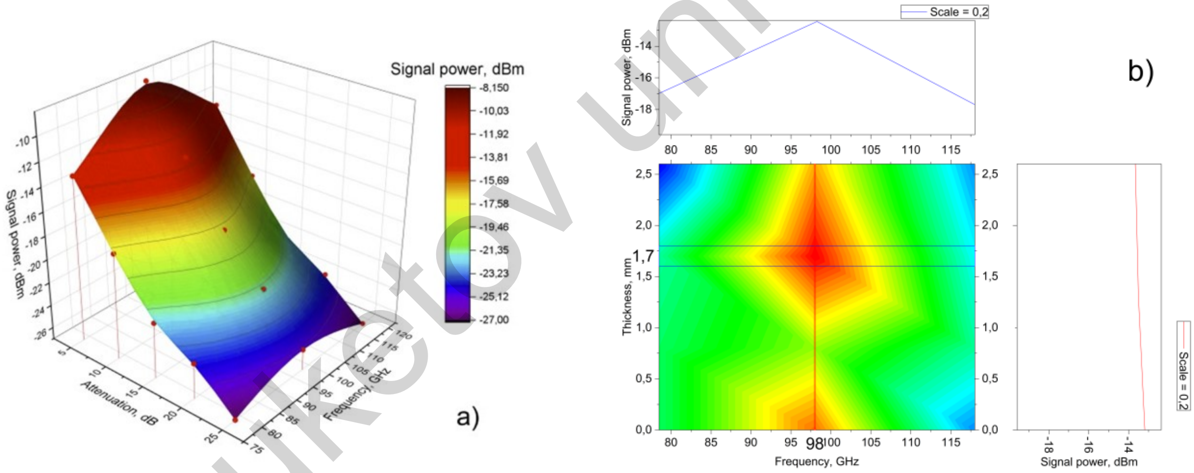


Fig.4. Recording "empty space" (a) and determining the most effective thickness of epoxy resin (b)

The next stage of the study focused on determining the absorption level of pure epoxy resin substrates of varying thicknesses. The purpose of this stage was to select the maximum thickness and determine its absorption properties to ensure that the substrate would not affect the research object. The measurements were carried out for films with a thickness of 0.8 mm, 1.7 mm and 2.6 mm, respectively. Registration was carried out at three discrete frequencies of 78.5 GHz, 98 GHz and 118 GHz. The results obtained are presented in Table 3.

Table 3. Measurement results of epoxy resin films of various thicknesses

f, MHz	Measurements, dBm			
	0 mm	0.8 mm	1.7 mm	2.6 mm
78500	-16.58	-16.58	-16.98	-19.59
98000	-13.19	-14.94	-12.37	-13.67
118000	-18.54	-16.98	-17.69	-18.54

A graphical representation of the dependence obtained after processing the data in Table 3 is shown in Figure 4b. A review of Figure 4b shows that the epoxy resin thickness of 1.7 mm is the most optimal. At this thickness, the substrate has a minimal effect on the magnitude of the EMI. Subsequently, when manufacturing the objects of study, we were guided by these results.

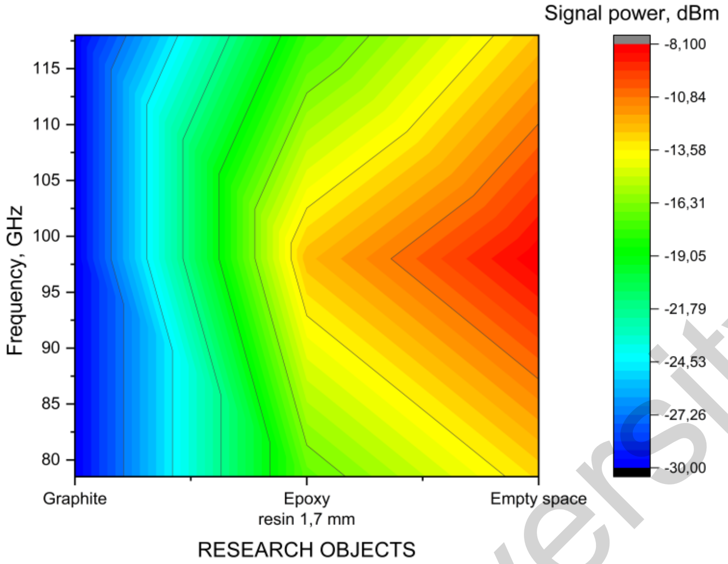


Fig.5. Comparison of study objects

The RAM was manufactured by blowing 10 mg of powdered graphite (grade GL-1) over the surface of the epoxy resin. Registration of the transmission coefficients of the EMI that passed through the samples was carried out at frequencies of 78.5 GHz, 98 GHz and 118 GHz. Figure 5 shows the results of comparing the data obtained for the case of "empty space" and epoxy resin with a thickness of 1.7 mm. From the figure we see that the registered signal that passed through the RAM corresponds to the value of -30 dBm. This indicates complete shielding of the EMI.

4. Conclusion

This study presents the results of measuring the transmission coefficient of graphite particles on the surface of epoxy resin. Signal registration was conducted at three different frequencies: 78.5 GHz, 98 GHz, and 118 GHz. It was determined that the most effective epoxy resin thickness is 1.7 mm, as this thickness has minimal impact on EMI levels across all tested frequencies. The results of experimental measurements of films of graphite particles on the surface of an epoxy substrate were obtained. The films were produced by dispersing 10 mg of graphite particles. The results demonstrated that the tested material completely shields EMI in the millimeter range.

Conflict of interest statement

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Makhanov K.M.: Conceptualization, Methodology, Validation, Investigation, Writing - Original Draft; **Smagulov Zh.K.:** Methodology, Resources, Investigation; **Burambaeva N.A.:** Data Curation, Writing - Original Draft, Supervision; **Assilbekova A.M.:** Writing Review & Editing, Supervision; **Soldatkhan D.:** Development of Facility and Measurements; **Kuttybek A.A.:** Data Curation, Visualization; **Suleimenova A.K.:** Data Curation, Resources; **Kenes T.K., Kenesbekov S.E.:** Development of Facility and Measurements, Investigation, Visualization; **Serikova A.A., Kenesbek B.Sh.**: Investigation, Visualization.

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