Shielding Properties of Electromagnetic Radiation Absorbers with Geometrical and Structure Heterogeneities

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ABSTRACT

Electromagnetic radiation (EMR) absorbers with geometrical and structure surface heterogeneities are investigated. Samples of shields based on dielectric and magnetic powder components and having different surface shape were prepared. Shielding properties of these absorbers such as EMR power attenuation, transmission (S21) and reflection (S11) coefficients in the frequency range of 0.5…18 GHz are shown. Dependencies of the shielding characteristics on the shield thickness and the amount of active substance were obtained. Comparative analysis of the developed novel EMR absorbers was conducted. The transmission coefficient down to -43 dB and the reflection coefficient down to -23 dB in the studied frequency range were obtained. An effective attenuation of electromagnetic power by the developed EMR absorbers has been concluded.

Keywords: Electromagnetic Radiation Absorbers, Shielding Construction Materials, Dielectric and Magnetic Properties, Geometrical Surface Heterogeneities, Attenuation of Power, S21, S11.

خصائص امتصاص الاشعاع الكهرومغناطيسي للأشكال الهندسية الغير متجانسة الاسطح

الخلاصة:

الهدف الاساسي من هذا البحث هو دراسة خصائص الدروع الماصة للأشعاع الكهرومغناطيسي (EMR)مع تغاير السطوح الهندسية وهياكلها. ولقد تم إعداد عينات من الدروع اساسها مواد عازلة ومسحوق مغناطيسي تم تصميمها بطرق مختلفة لتشكيل السطوح. وقد تم توضيح خصائص هذه الدروع الماصة لمعاملات قدرة التوهين، الانتقال (S21) والانعكاس (S11) في نطاق التردد 0.5

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الى 18 غيغاهيرتز. وتم الحصول على خصائص التدريع بالاعتماد على سمك وكلفة وفعالية المادة المستخدمة. وقد تم الاخذ بنظر الاعتبار الخصائص النسبية للدروع الحديثة المختلفة والماصة للأشعاع الكهرومغناطيسي (EMR) . وقد تبين ان معامل التوهين للأشعاع الكهرومغناطيسي يصل الى 43- ديسيبل وان التقليل من معامل الانعكاس يصل إلى 23- ديسيبل في نطاق الترددات المستقبلة. ولذلك تم الاخذ بنظر الاعتبار قوة معامل التوهين من قبل هذه العينات.

INTRODUCTION

Shielding materials integration with building constructions is essential for good functioning of an equipment and personnel under conditions of a widespread use of various sources of electromagnetic radiation. The inability to stop the usage of beneficial effects of such resources determines the specific tasks assigned to the scientists, designers and production staff, to ensure the safe use of such equipment. A wide frequency spectrum of EMR sources determines the need for broadband EMR screens. Among the existing methods and ways of EMR screens design we can find many different techniques and engineering solutions based on a variety of materials. However, most of them have a narrow operating frequency range, are complicated to manufacture or involve expensive components or raw materials. Therefore, the urgent task now is to develop low-cost and high-tech shields and EMR absorbers which could be easily used to create shielded premises – to solve the problems of TEMPEST threats for information, electromagnetic compatibility of electronic equipment, safe work of a personnel working with SHF sources and computer users, etc.

Basic requirements to microwave absorbing materials may be summarized as follows [1]:

- a high attenuation of EMR;
- a small external surface reflection, especially in case of plane absorbers;
- a low weight;
- a stability of EMR shielding effectiveness during exploitation;
- ease of manufacture and assembly.

The attenuation of the energy of electromagnetic wave by radioabsorbing materials is provided by their dielectric, conductive and magnetic properties. A common approach is to use a combination of different materials in various forms – powder, fibers, flakes etc – with a variation of concentration, ratio and dimensions [2, 3]. When the appropriate absorber material parameters match with the wave parameters of the medium in which the absorber (working area) is placed, the reflection coefficient is low and the EMR shielding effectiveness is high. Another way to reduce the reflectivity of an absorber is to use a special design – a specified thickness, multiple layers, shaped-surface and their combination [4, 5]. All the mentioned approaches are aimed at broadening the operating frequency range, increasing the shielding efficiency and decreasing the reflectivity of the absorber though all of them have their virtues and shortcomings. The shielding effectiveness of such absorbers can reach up to 35...50 dB with the reflection coefficient less than -10 dB.

The aim of this work is the study and development of highly efficient combined EMR absorbers that can attenuate EMR over a wide frequency range with a low reflection coefficient.

Electromagnetic shielding. Main equations of EMR absorption

Electromagnetic absorbers have a number of applications, such as are the anechoic chambers used for compliance testing of apparatus and systems instead of open area test sites, reduction of the radar cross sections of objects, improvement of the radiation pattern of antennas, damping of resonances and spurious electromagnetic radiation in metal shielding constructions, etc [6]. For the purpose of EMR shielding, the last application is evidently good for an improvement of a shielded room performance. The high conductivity of metal walls works to trap the electromagnetic energy penetrated through the shield discontinuities (which may be viewed as traveling back and forth within the shielded volume). Materials capable of effective dissipation of such energy in the shielded area can considerably help in the improvement of shielding effectiveness.

Effective radioabsorbing materials are very important to ensure a good performance of a radio frequency (RF) anechoic chamber. Microwave absorbers are the main components used in an anechoic chamber to eliminate reflected signals. There are two common RF absorber types: for the microwave frequency range (1GHz to 300GHz) and for the lower frequency range (30MHz to 1000MHz). Absorber's surface shape strongly affects their performance. Many types of designs are applied for the RF absorbers: the layer type, pyramidal, wedge, walkway, convoluted, ferrite tiles, oblique incident and metamaterial absorbers. Pyramidal absorbers are commonly applied for the frequency range above hundreds of megaherz [7].

The most important characteristics influencing the materials behavior on microwaves are the following: complex permittivity ($\varepsilon=\varepsilon'-j\varepsilon''$), complex permeability ($\mu=\mu'-j\mu''$), dielectric loss (ε'), magnetic loss (μ'), dielectric loss tangent ($tg\delta_{\varepsilon}=\varepsilon''/\varepsilon'$), magnetic loss tangent ($tg\delta\mu=\mu''/\mu'$), wave impedance ($Z=\sqrt{\frac{\mu \cdot \mu_r}{\varepsilon \cdot \varepsilon_r}}$). The behavior of a material on microwaves may be considered as inactive, when

$$\mu'' << \mu'(\mu'' \to 0) \quad \ldots \quad (1)$$

$$\varepsilon'' << \varepsilon'(\varepsilon'' \to 0) \quad \ldots (2)$$

When

the values $\varepsilon', \varepsilon'', \mu', \mu''$, are comparable, the material exhibits an active behavior on microwaves.

The most important microwave characteristics of an absorbing material are the attenuation (3) and the coefficient of reflection (4)

$$\alpha = 10\lg\frac{P_t}{P_i}, dB \qquad \ldots (3)$$

$$r = \frac{Z_2 - Z_1}{Z_2 + Z_1}, \qquad \ldots (4)$$

Where

P_t – the power of the electromagnetic wave without the shield;
P_i – the power of the electromagnetic wave with the shield;
Z_1 – the wave impedance of the medium 1;
Z_2 – the wave impedance of the medium 2.

Carbon is a very common material used in microwave absorbers, as it provides a high reflection loss performance due to its high conductivity. There are many ways to increase the pyramidal microwave absorber performance such as using the material with high concentration of carbon, using the new hybrid pyramidal shape, making an array pyramidal microwave absorber and adding the met material structure to the pyramid.

Commercial microwave absorbers are usually made of plastic foamed-based materials like polystyrene or polyurethane impregnated with carbon powder and dried. Besides, there are also many researches on alternative materials, such as carbon nanotube composites, ferrite absorbers, ferroxide films and other polymers materials [8, 9].

Carbonaceous materials as structure elements of EMR absorbers

Carbonaceous powder (i.e. shungite) fillers are widely used as a base for electromagnetic absorbers in microwave [10]. Carbon molecules cover silicon molecules in shungite structure and form a carbon conductive mesh. Shungite conductivity value ranges from $3{,}53\text{x}10^{-3}$ to $3{,}29\text{x}\ 10^{-2}$ sm. This value depends on carbon content in shungite. If the concentration of carbon is high, then the conductive grid size is greater and, therefore, the value of the electrical conductivity of this material is greater also.

Thus, the use of schungite for EMR shields results in their high shielding effectiveness. An increasing amount of the shielding material improves its ability to attenuate the electromagnetic radiation power.

Shungite composite materials used to design EMR shields can be divided into two classes:

- Construction materials, which include concrete, brick, mortar. Materials provide attenuation of electromagnetic energy in the frequency range of more than 100 MHz at a level of 100 dB. Specifications for schungite bricks and cement were developed. In terms of their physical and mechanical characteristics, schungite construction materials are not inferior to traditional building counterparts. Shungite materials were tested in the construction (concrete panels in ceilings, brick walls) and found to comply with the existing building requirements.

- Materialsfor reconstruction, such as plaster and putty, allowing construction to convert into a conventional shielded. Mastic can provide a shielding effect of at least 30 dB in the frequency range above 30 MHz with a layer thickness of 2-3 cm [11].

Experiment

To study the influence of the geometry of the electromagnetic screen surface on its performance and to reduce the reflection of electromagnetic waves, an experimental technique to create shungite-concrete monolithic modules has been developed.

Sample preparation

To solve the problem described in the aim of this paper two samples were manufactured based on pyramidal EMR absorbers. The height of the pyramidal base (L) is about 50 mm (Fig. 1, 2) that corresponds to the minimum wavelength in microwave range of frequency. It is a necessary condition to satisfy in order to minimize the reflection from the surface of an EMR absorber (5)

$$L \approx \lambda = c/f, \text{ m} \qquad ...(5)$$

where

L – high of pyramid or other irregularities;
λ – wavelength, m;
$c=3*10^{-8}$ – speed of light, m/sec;
f – frequency, Hz

The first type of samples is a hollow pyramidal shaped surface structure with a EMR absorbing coating. Carbonaceous mineral of natural origin (shungite) is used as a basic element of the coating. The aforementioned powder filler with the particles size less than 0.5 mm is embedded into the artificial inorganic binder.

We used industrially produced pulp moulded forms intended to transport oval geometric objects with a diameter of about 4 - 5 cm as a substrate for the coating. The shape and appearance of the substrate are shown in Figures 1, 2. The thickness of the cellulose base (d) is not more than 2 mm due to the technology of its manufacturing. But the structural strength after application of the EMR absorber layer requires the thickness is not less than minimal allowable.

The absorbing coating was produced by mixing the powders of shungite and cement in a weight ratio of 1:1 in aqueous solutions of alkaline earth metals salts of 30% mas. concentration. The selected concentration of water-salt solution is equilibrium and is intended to stabilize the shielding characteristics in time [12].

The second sample of EMR absorber is a filled pyramidal structure. Modular shield design was made by filling a rectangular wooden casing with the size of 0.4x0.3 m^2 with the absorbing composition. For such samples the bottom was made of the pyramidal shaped forms of a pressed cellulose pulp. The surface of such a module is aligned with the surface of the casing and its minimum thickness is about 8 - 10 mm.

The appearance of the absorber is shown in Figure 3. The weight of the filled construction is 3.5 kg. The weight of the first coated sample is 0.4 kg.

Technique of shielding characteristic measurement

Measurement of shielding characteristics was performed in the frequency range of 0.5 - 18 GHz.

To measure the shielding characteristics of samples the following measuring instruments were used:

- Frequency Sweep Generator FSG -14;
- Waveguide horn antenna section of 280x360 mm;
- Scalar network analyzer.

A signal, which is proportional to the power incident on the load, is released by a directional detector of an incident wave. The attenuation introduced by the test sample is determined by the ratio of signals allocated by the detectors of the incident and reflected waves. The transmission coefficient is determined by

$$S_{21} = \sqrt{\frac{U_{pass}}{U_{inc}}}, \quad \ldots (6)$$

Where

U_{pass} – the voltage amplitude of the wave behind the sample;

U_{inc} - the voltage amplitude of the incident wave. Attenuation of the EMR is a reciprocal of the transmission coefficient.

The signal that is reflected from the sample is allocated by the directional detector of the reflected wave.

The reflection coefficient is determined by

$$S_{11} = \sqrt{\frac{U_{ref}}{U_{inc}}}, \quad \ldots (7)$$

Where

S_{11} – the magnitude of the voltage EMW reflection;

U_{ref} – the amplitude of the detected voltage of the reflected wave.

Horn antennas served as the transmitter and the receiver of the signal. Calibration of the instrument over the entire operating frequency range was performed using the standard technique after setting the frequency sweep and the level of the incident power.

Power levels measurement technique

Measurement of power levels, passing through the shield were carried out with the setup, which consists of transmitting and receiving antennas, a generator of electromagnetic radiation in microwave frequency range and a power meter. The generator and the transmitting antenna were connected with each other by the waveguide, the receiving antenna and the power meter – through a thermo electrical transformer.

The technique of measurement of the EMR power levels passing through the shield included two steps. There was a calibration on the first step. The generator power levels in the frequency range 0.8... 18 GHz corresponding to the power levels of the electromagnetic radiation at the receiver antenna at 1 mW, 2 mW, 3 mW, 4 mW and 5 mW were determined. In order to increase the further measurements accuracy the calibration measurement was repeated ten times at each frequency. The transmitting and receiving antennas were placed at a distance equal to the thickness of a sample planned to study.

On the second step the studied sample was placed between the antennas. After that the electromagnetic radiation with power levels of 1 mW, 2 mW, 3 mW, 4 mW and 5 mW was formed at the transmitting antenna using the generator and further shots of the power meter indications were taken. The relative measurement error was ± 5%.

Interpretation of the results and discussions

The developed samples were tested for the presence of EMR absorbing properties on microwaves. Also, a comparative analysis of the shielding properties of the samples was made.

Measurement of shielding characteristics was performed in the frequency range of 0.5…18 GHz. For samples of the first type the shielding characteristics in the investigated frequency range are shown in Figures 3 - 5.

The EMR power reduction produced by the developed samples was measured in the range of 1...5 mW. The attenuation of EMR power is shown in Figures 6, 7.

It was found that the EMR attenuation determined from the transmission coefficient varies from 7 dB to 30 dB in the studied frequency range that is explained by the thickness of the samples (8 - 10 mm) on the basis of the pyramids. Ccontingently, the entire measurement frequency range can be divided into two intervals. As we can see in Fig. 4, the transmission coefficient of the sample with a coated pyramidal base sharply decreases from -15 to -30 dB in the frequency range of 0.7…2.5 GHz. In the frequency range of 3…18 GHz the transmission coefficient fluctuates around -25 dB. The sample of a filled pyramidal structure possesses the transmission coefficient with a sharp reduction from -10 to-40 dB in the frequency range of 0.7…3.5 GHz. In the frequency range of 6…18 GHz the transmission coefficient fluctuates around -30 dB. Thus we can see a high shielding efficiency of both samples on microwaves. The main effect for the EMR absorber samples attenuation ability is provided by the presence of the carbonaceous powder filler because of its conductive properties and a heterogeneous molecular structure. The incident electromagnetic wave induces currents within the conductive inclusions of the composite thus initiating transformation of the electrical power into heat losses. Another mechanism of the reflected energy decreasing is connected with the shape of the absorber surface. It is known, that pyramidal horns at the surface with their size comparative with the wavelength of the incident electromagnetic wave provide attenuation of EMR due to multiple reflections between the surfaces of the pyramids.

It has been found that the reflection coefficient is about -15 dB in the frequency range of 3...12 GHz, and increases to -5 dB in the frequency ranges of 0.5…3 GHz and 13...18 GHz for both studied samples (Fig. 5, 6). The relatively low reflection coefficient for both samples is mainly determined by the pyramidal shape of surface.

Besides, a certain amount of silicon oxide in shungite possesses dielectric losses for the incident electromagnetic power providing additional energy dissipation.

The first type sample provides a total attenuation of the EMR power in the frequency range from 10 to 18 GHz (Fig. 7), the second type sample provides a total attenuation of EMR power in the frequency range from 6 to 18 GHz (Fig. 8). This is due to the fact that the thickness of the surface layer of the second type sample exceeds the wavelength of the electromagnetic wave in the frequency range 6…18 GHz.

CONCLUSIONS

The obtained results of the shielding characteristic measurements for the developed EMR absorbers with geometrical and structure heterogeneities allow to suggest the application of carbonaceous powder composite as an effective EMR absorbing coating for pyramidal shaped bases. The surface geometrical heterogeneities can reduce the reflection coefficient, and physical-chemical properties of the carbonaceous composite on the base of shunpike provide high EMR attenuation. The availability of components and ease of fabrication of such type of absorbers allow us to suggest their application in the construction of EMR protected rooms and to create a favorable operating environment for the personnel working with radioelectronic equipment. A comparative analysis of two studied types of constructions suggests a possibility to reduce the material consumption and weight of the absorber with keeping of the high shielding efficiency.

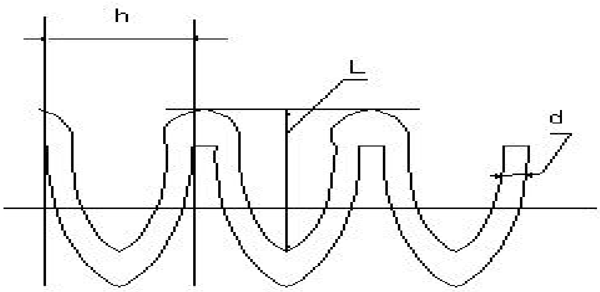

Figure (1) Geometric parameters of the pyramidal base form

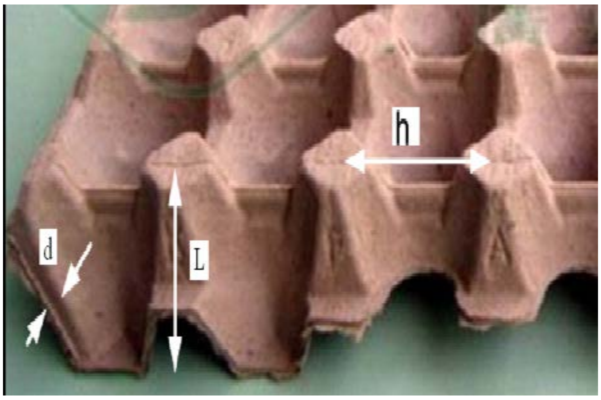

Figure (2) Appearance of the pyramidal base form

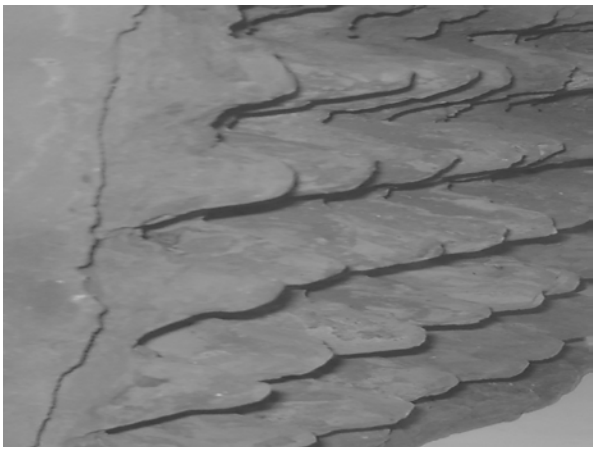

Figure (3) Common view of the filled pyramidal shielding module

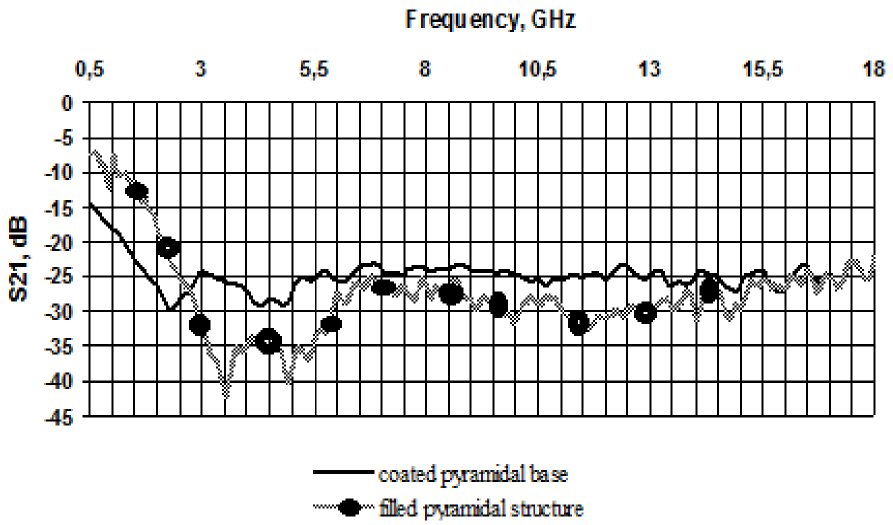

Figure (4) Frequency dependence of the transmission coefficient in the frequency range 0.5 ... 18 GHz for radioabsorber modules

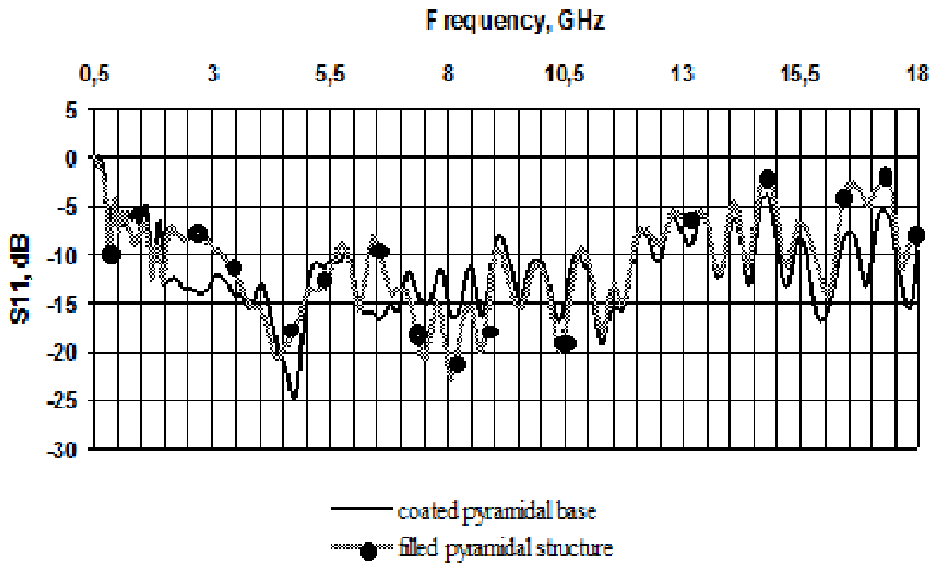

Figure (5) Frequency dependence of the reflection coefficient in the frequency range of 0.5 ... 18 GHz for the filled pyramidal shielding module

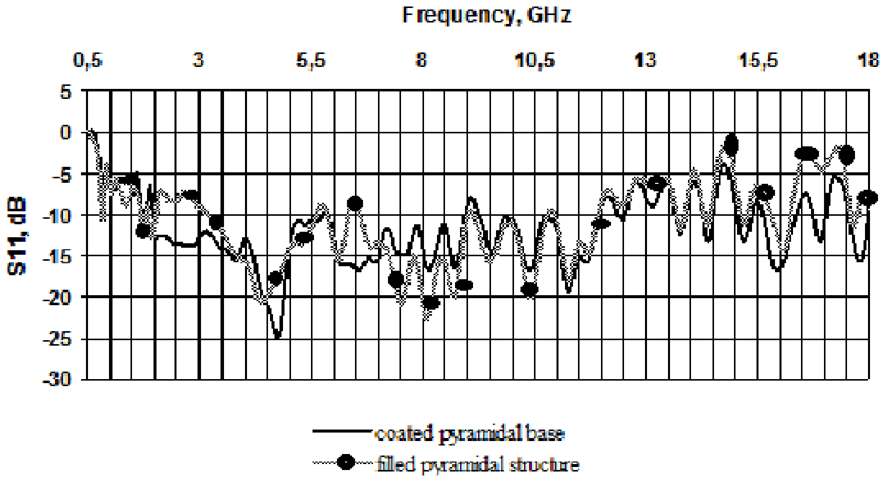

Figure (6) Frequency dependence of the reflection coefficient in the frequency range of 0.5 ... 18 GHz for the filled pyramidal shielding module with metallic reflector behind the sample

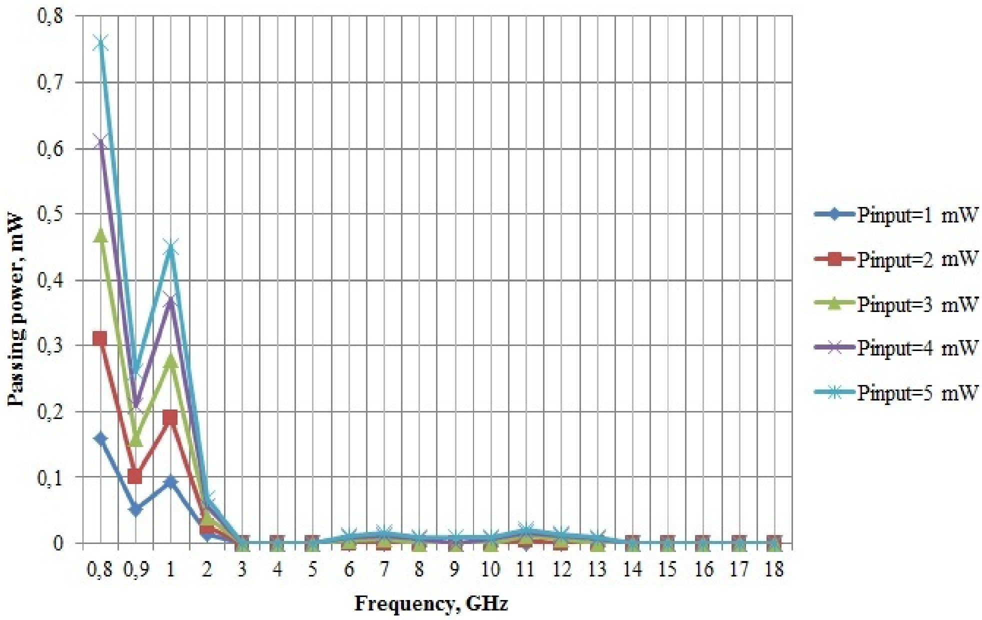

Figure (7) Frequency dependence of the passing power in the frequency range of 0.8 ... 18 GHz for the coated pyramidal absorber

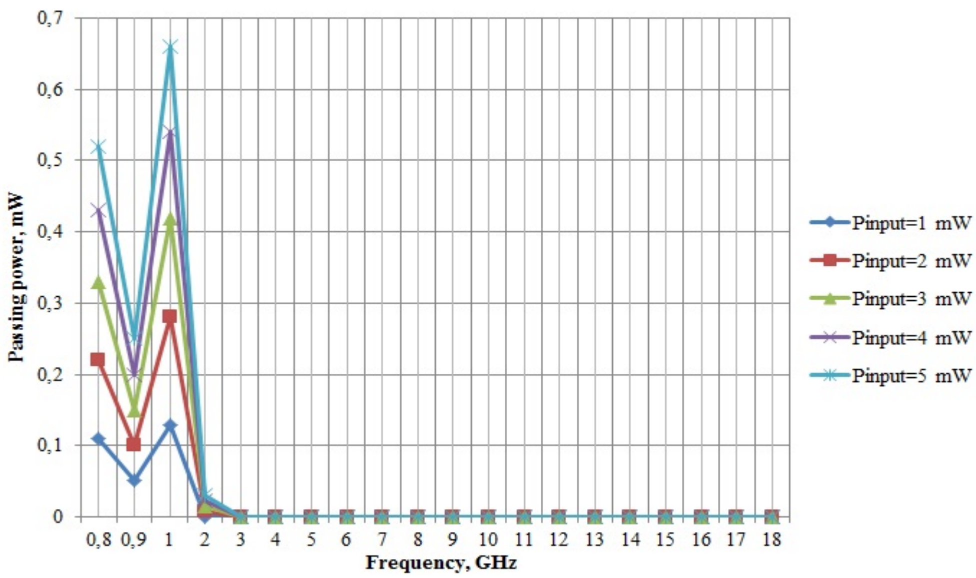

Figure (8) Frequency dependence of the passing power in the frequency range of 0.8 ... 18 GHz for the filled pyramidal shielding module

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