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DEVELOPMENT AND STUDY OF MULTILAYER ELECTROMAGNETIC RADIATION SHIELDS BASED ON POWDERED OXIDE-CONTAINING MATERIALS

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Abstract. The electromagnetic shields in the form of two-layer structures, the surface layer of which was the composite material with filler based on powdered titanium dioxide, and the inner one was the composite material with filler based on iron oxide, have been developed. The electromagnetic radiation reflection and transmission characteristics of the developed shields have been studied in the frequency range 0.7-142.8 GHz depending on the content of their inner layers. It has been found that electromagnetic radiation reflection and transmission coefficient values in the frequency range 0.7-142.8 GHz of the developed shields are –4.0…–27.0 dB and –10.0…–40.0 dB respectively. It has been experimentally proved that by impregnating by the calcium chloride aqueous solution of the powdered material that is part of the inner layer of such shields, it is possible to reduce by 5.0...45.0 dB of their electromagnetic radiation transmission coefficient values in the frequency range 2.0...26.0 GHz.

Keywords: electromagnetic radiation, iron oxide, shield, titanium dioxide

1. Introduction

The work [1] presents the study results of the laws of interaction of electromagnetic radiation in the frequency range 0.7…17.0 GHz with two-layer structures based on powder materials containing transition metal oxides (titanium, iron), depending on the layer thickness of these structures, which varied from 0.3 to 1.0 cm. It has been determined that the best shielding characteristics in the specified frequency range (values of electromagnetic radiation reflection coefficient, varying from –4.0 to –18.0 dB at values of the electromagnetic radiation transmission coefficient, varying from –5.0 to –20.0 dB), had the structures with a layer thickness of 0.5 cm. To develop the studies, the results of which are presented in [1], the established aim of this work was an experimental assessment of the possibility of improving the shielding characteristics of two-layer structures based on powdered materials containing transition oxides metals (titanium, iron), by including into their composition an aqueous solution of electrolyte (calcium chloride). In [2-6], the promise of this electrolyte using as part of electromagnetic shields are justified, in view of the following features:

– characterized by high values of electrical conductivity, due to which it provides energy loss of electromagnetic radiation interacting with it;

– is hygroscopic, due to which the electromagnetic radiation reflection and transmission coefficient values of the shields, which include this electrolyte solution, don't significantly depend on external factors (in particular, temperature and humidity).

To achieve the aim, the following objectives have been solved:

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1) on the basis of powdered titanium dioxide, iron-containing powdered material, and calcium chloride aqueous solution, electromagnetic shields have been made in the form of two-layer structures, the thickness of each layer of which was 0.5 cm;

2) the laws of the interaction of electromagnetic radiation in the frequency range 0.7…142.8 GHz with made electromagnetic shields have been studied, for which their electromagnetic radiation reflection and transmission characteristics in the specified frequency range have been obtained.

It should be noted that in the framework of the present work, the electromagnetic radiation reflection and transmission characteristics of the made electromagnetic shields have been obtained in an extended frequency range, compared with the frequency range in which similar characteristics were obtained, presented in other papers of the same science field [1,7-15].

2. Materials and Methods

For research, the electromagnetic shields samples have been made in the following form:

1) two-layer structure, the inner layer of which (relative to the electromagnetic radiation propagation front) has been made on the basis of iron-containing powdered material and gypsum binder, and the outer one was based on powdered titanium dioxide and gypsum binder (sample 1);

2) two-layer structure, the inner layer of which (relative to the electromagnetic radiation propagation front) has been made on the basis of an iron-containing powdered material, impregnated to saturation with calcium chloride aqueous solution, and a gypsum binder, and the outer one was based on powdered titanium dioxide and gypsum binder (sample 2).

Samples were made in accordance with the methodology, which includes the following steps.

Step 1. Preparation of a gypsum binder by mixing powdered gypsum with water (in case of sample 1 and sample 2 making).

Step 2. Uniform distribution of an iron-containing powdered material over the volume of the prepared gypsum binder by mixing the first one with the second one using a laboratory mixer (in case of sample 1 making).

Step 2.1. Preparation of calcium chloride water solution (in case of sample 2 making).

Step 2.2. Impregnation to saturation with calcium chloride aqueous solution of iron-containing powdered material (in case of sample 2 making).

Step 2.3. Uniform distribution of powdered iron-containing material impregnated to saturation with calcium chloride aqueous solution over the volume of the prepared gypsum binder by mixing the first one with the second one using a laboratory mixer (in case of sample 2 making).

Step 3. Filling by the obtained mixture of the press-form, characterized by a rectangular section (in case of sample 1 and sample 2 making).

Step 4. Drying the mixture in the press-form for 2 hours (in case of sample 1 making) or for 3 hours (in case of sample 2 making) under standard conditions.

Step 5. Repeat Step 1 (in case of sample 1 and sample 2 making).

Step 6. Uniform distribution of powdered titanium dioxide over the volume of the prepared gypsum binder by mixing the first one with the second one using a laboratory mixer (in case of sample 1 and sample 2 making).

Step 7. Distribution of the obtained mixture with a spatula over the surface of the composite material located in the press-form, which is a result of step 4 (in case of sample 1 and sample 2 making).

Step 8. Drying the mixture distributed during Step 7 under standard conditions (in case of sample 1 and sample 2 making).

Step 9. Removing the resulting structure from the press-form (in case of sample 1 and sample 2 making).

To measure the electromagnetic radiation reflection and transmission coefficients values in the frequency range 0.7…142.8 GHz of the made samples, we have used the equipment developed on the basis of the Scientific and Educational Innovation Center for Microwave Technologies and their Metrological Support of the Educational Institution "Belarusian State University of Informatics and RadioElectronics":

1) vector network analyzer Anritsu MS 4644B in combination with two horn antennas ETS-Lindgren 3115 (for measurements in the frequency range 0.7…18.0 GHz);

2) vector network analyzer Anritsu MS 4644B in combination with two horn antennas P6-30 (for measurements in the frequency range 18.0…25.95 GHz);

3) panoramic standing wave coefficient meter P2-65 in combination with two horn antennas P6-10A (for measurements in the frequency range 25.95…37.5 GHz);

4) panoramic standing wave coefficient meter P2-120 in combination with two horn antennas from the AST set (for measurements in the frequency range 37.5…53.57 GHz);

5) panoramic standing-wave coefficient meter P2-121 in combination with two horn antennas from IYa 53-78 set (for measurements in the frequency range 53.57…78.33 GHz);

6) panoramic standing wave and attenuation coefficient meter PP2-01 in combination with two horn antennas from the IYa 78-118 set (for measurements in the frequency range 78.33…118.1 GHz);

7) panoramic standing wave and attenuation coefficient meter P2-123 in combination with two horn antennas 2P1 (for measurements in the frequency range 118.1…142.8 GHz).

Measurements using the indicated equipment have been carried out in an automated mode and included two stages:

1) device calibration;

2) registration of the values of the measured parameter.

Calibration before measuring electromagnetic radiation reflection coefficient values of the samples was carried out using a short circuit, which was connected instead of the receiving antenna and which was a metal plate.

Electromagnetic radiation reflection coefficient values of the samples were measured in two modes:

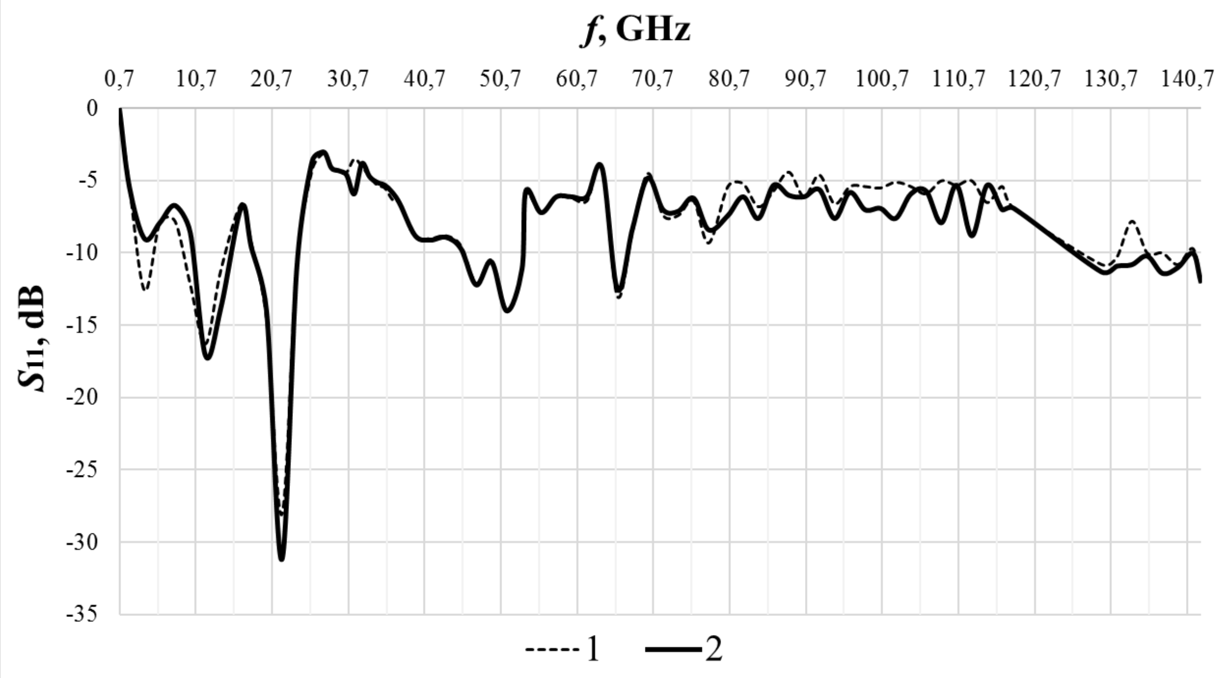
1) matched load mode, in which the sample was placed between the transmitting antenna and the matched load (mode 1);

2) short circuit mode in which the test sample was placed between the transmitting antenna and the short circuit (mode 2).

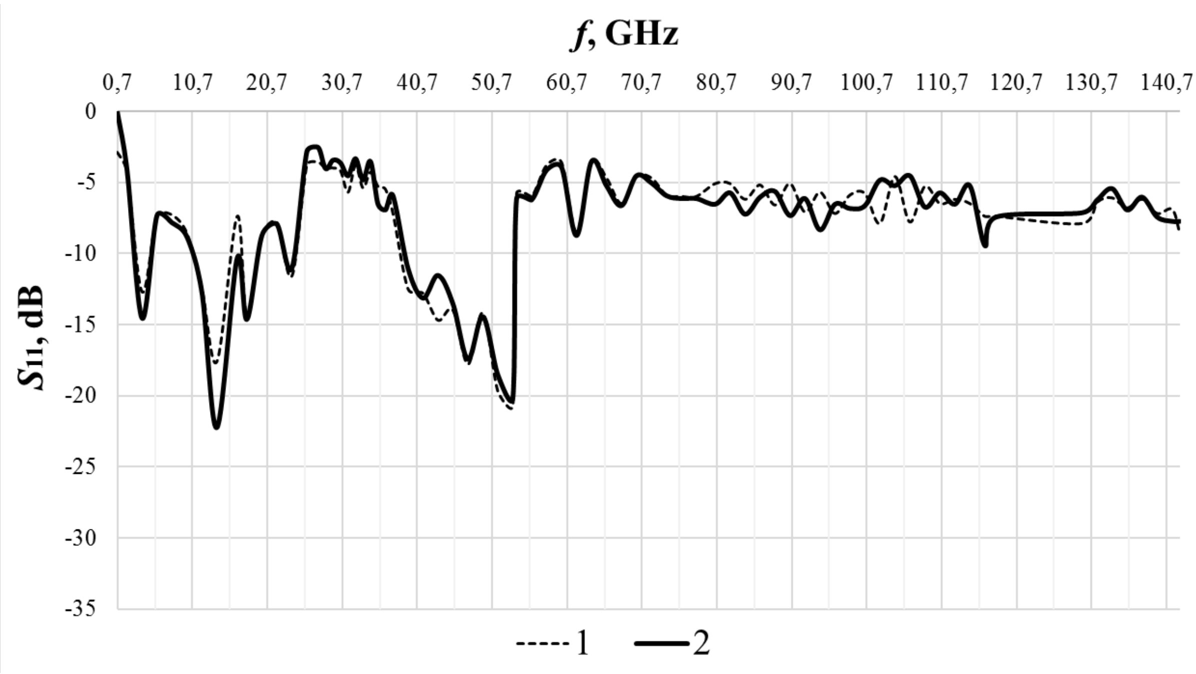
Calibration before measuring the electromagnetic radiation transmission coefficient values of the samples was carried out using a matched load, which was connected instead of the receiving antenna. Upon calibration completion, before taking measurements of electromagnetic radiation transmission coefficient values of the samples, a receiving antenna was connected instead of the matched load, after which the sample was placed between the transmitting and receiving antennas.

3. Results and Their Discussion

Electromagnetic radiation reflection coefficients frequency dependences in the range 0.7…142.8 GHz of the made and studied samples, obtained on the base of the measurement results, are presented in Fig. 1.



a



b

Fig. 1. Electromagnetic radiation reflection coefficient frequency dependences in the range 0.7…142.8 GHz of sample 1 (*a*) and sample 2 (*b*), measured in the modes 1 (line 1) and 2 (line 2)

From Fig. 1 it follows that electromagnetic radiation reflection coefficient values in the frequency ranges 0.7…18.0 GHz, 24.0 …142.8 GHz of sample 1 vary from –5.0 to –15.0 dB. The minimum value of the parameter for sample 1 is –28.0 dB and corresponds to the electromagnetic frequency of 22.0 GHz. This may be due to the fact that electromagnetic radiation energy o the indicated frequency is absorbed to the greatest extent by the iron-containing powdered material that is part of the inner layer of the made and studied samples (the phenomenon of ferromagnetic resonance) [16,17].

Electromagnetic radiation reflection coefficient values in the frequency range 0.7…56.0 GHz of sample 2 vary in the range from –5.0 to –20.0 dB and in the frequency range 56.0…142.8 GHz – in the range from –5.0 to –10.0 dB. It was found that the electromagnetic radiation reflection coefficient in the frequency of 22.0 GHz for sample 2 is higher by 20.0 dB than for sample 1, on the basis of which it can be concluded that impregnation of the powdered iron-containing material to saturation with calcium chloride aqueous solution leads to a change in electromagnetic radiation frequency at which the maximum absorption of its energy is observed (ferromagnetic resonance). This is due to the change in the relative magnetic permeability of the iron-containing powdered material due to an increase in its moisture content [18,19].

The electromagnetic radiation reflection coefficient in the frequency range 39.5…53.5 GHz of sample 2 is 5 dB lower than sample 1, which is most likely due to the SPE-effect [20]. Electromagnetic radiation reflection coefficient in the frequency range 129.5…142.8 GHz of sample 2 exceeds by 3 dB the value of the same parameter of sample 1, which is most likely due to an increase in the energy level of electromagnetic radiation of the specified frequency range absorbed by the iron-containing powdered material, as a result of its impregnation to saturation with an aqueous solution of calcium chloride.

Electromagnetic radiation reflection coefficient values in the frequency range 0.7…20.0 GHz, 53.5…129.5 GHz for samples 1 and 2 are almost similar, based on which we can conclude that the impregnation to saturation with calcium chloride aqueous solution of iron-containing powdered material used for the manufacture of the studied structures, leads to a change in the values of their electromagnetic radiation reflection coefficient at the frequency of 22.0 GHz, i.e., at the ferromagnetic resonance frequency, as well as in the frequency ranges 24.0…53.5 GHz, 129.5…142.8 GHz.

On the frequency dependence of electromagnetic radiation reflection coefficient in the range 0.7…142.8 GHz of sample 1, we can arbitrarily single out one resonance curve, the central frequency of which is 22 GHz. In the frequency dependence of electromagnetic radiation reflection coefficient in the range 0.7…56.0 GHz of sample 2, two resonance curves can be conditionally distinguished. The center frequency of the first of these curves is 14.0 GHz and of the second one is 53.5 GHz. The presence of a conditionally distinguished resonance curve with a central frequency of 14.0 GHz in the frequency dependence of electromagnetic radiation reflection coefficient of sample 2 is most likely due to the fact that the electromagnetic radiation of the indicated frequency is absorbed to the greatest extent by iron-containing powdered material impregnated to saturation with calcium chloride aqueous solution. Based on this, it can be assumed that impregnation of iron-containing powdered material to saturation with calcium chloride aqueous solution leads to a decrease from 22.0 to 14.0 GHz of the ferromagnetic resonance frequency characteristic of such material.

It was found that electromagnetic radiation reflection coefficient values of the studied samples, measured in mode 1, practically don’t differ from their electromagnetic radiation reflection coefficient values, measured in mode 2. This is due to the fact that electromagnetic radiation reflected from the metal plate used during measurements in mode 2, was reflected by the surface of the inner layer of the studied samples and absorbed in their thickness.

Electromagnetic radiation transmission coefficients frequency dependences in the range 0.7...142.8 GHz of the made and studied samples, obtained on the base of the measurements results, are presented in Fig. 2.

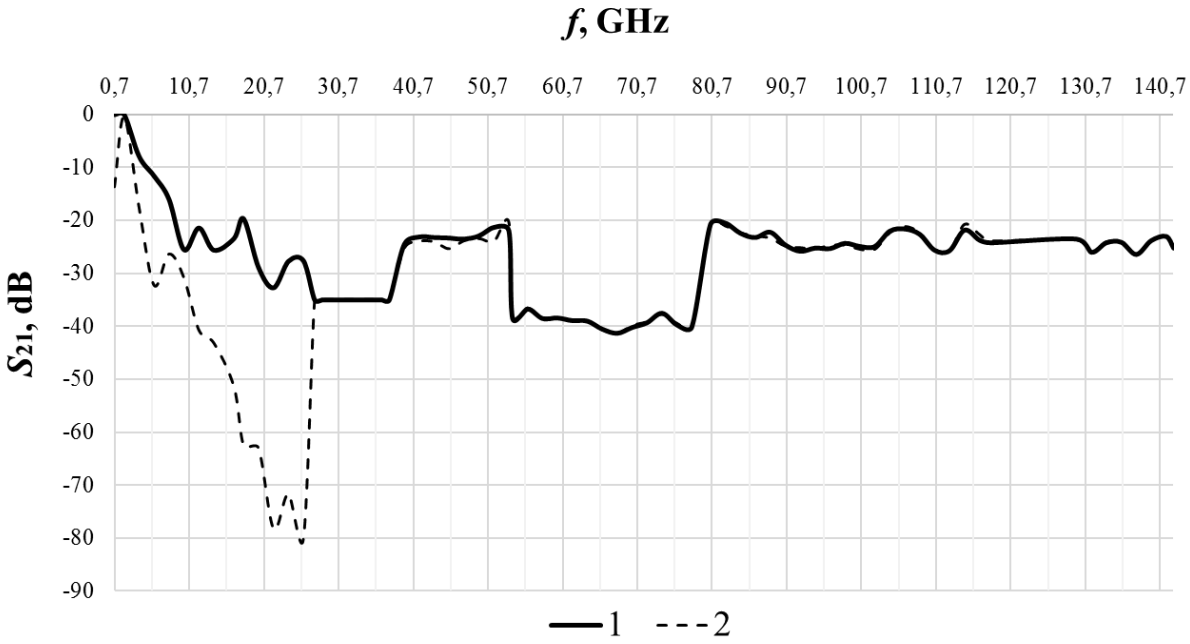


Fig. 2. Electromagnetic radiation transmission coefficient frequency dependences in the range 0.7…142.8 GHz of sample 1 (line 1) and sample 2 (line 2)

From Fig. 2 it follows that electromagnetic radiation transmission coefficient values of sample 1 vary in the range from –10.0 to –35.0 dB in the frequency range 0.7…26.0 GHz, in the range from –20.0 to –40.0 dB in the frequency range 26.0…150.0 GHz, for sample 2 – in the range from –10.0 to –40.0 dB in the frequency range 0.7…2.0 GHz, in the range from –35.0 to –80.0 dB in the frequency range 2.0…26.0 GHz, in the range from –20.0 to –40.0 dB in the frequency range 26.0…150.0 GHz. It was found that by impregnating the iron-containing powdered material to saturate with an aqueous solution of calcium chloride, used to make the inner layer of the studied structures, it is possible to reduce by 5.0…45.0 dB of their electromagnetic radiation transmission coefficient values in the frequency range 2.0…26.0 GHz. This decrease is due to relaxation and polarization energy losses of electromagnetic radiation in the frequency range 2.0…26.0 GHz due to its interaction with iron-containing powdered material impregnated to saturation with calcium chloride aqueous solution [2].

4. Conclusions

Based on the obtained results, it can be concluded that developed and studied in the framework of this work electromagnetic shields in the form of two-layer structures containing powdered transition metal oxides (titanium, iron) and building material (gypsum) seem promising for use in architectural electromagnetic shielding systems (creating internal partitions for shielded rooms, cladding panels for the walls of such rooms, etc.). Also, such materials can be used to reduce the energy of electromagnetic radiation reflected from the walls of rooms shielded with metal materials.

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