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# ELECTROMAGNETIC SHIELDS BASED ON POWDERED COAL-CONTAINING MATERIALS

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The monograph presents the methods for manufacturing of electromagnetic shields based on powdered charcoal and activated and coconut coals. The research results of electromagnetic radiation transmission and reflection characteristics of such shields are presented.

Designed for engineering, technical and scientific workers in various fields of industry, as well as for undergraduate and graduate students studying aspects of creating technical means of information protection.

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# INTRODUCTION

Currently, the development of information protection means against leakage through the channel of secondary electromagnetic radiation and inductions, as well as means to reduce the radar visibility of ground objects is associated with the creation of new and improvement of the already used radio absorbing and radio shielding materials and products based on them (electromagnetic shields). Most often, such materials are characterized by high conductivity. They are made in the form of metal sheets and nets, thin-film coatings, dispersed solutions, solid-state composite materials. The main disadvantage of metal sheets and grids is the high electromagnetic radiation reflection coefficient, and therefore such materials are potential sources of passive interferences for electronic devices near which they are located. Thin-film conductive coatings in certain situations may be inconvenient to use or impossible to use, which is associated with the technology, in particular, with the conditions for their application to shielded devices. The use of dispersed solutions is very promising, since the ratio of the components of these solutions, and hence their shielding properties, can be controlled during operation. However, such solutions are usually characterized by a narrow range of operating temperatures.

In connection with the foregoing, solid-state composite materials with conductive fillers in the form of fibers and / or powders are most widely used for the manufacture of electromagnetic shields. Such materials are heterogeneous radio absorbing media and are characterized by low values of electromagnetic radiation transmission coefficient. Composite materials with fillers in the form of powders are more preferred for use compared with materials with fillers in the form of fibers. This is due to the greater manufacturability of the former as compared to the latter (a uniform distribution of powders over the volume of the binder is realized over a shorter period of time). Modern composite materials with conductive powdered fillers (shungite, graphite, carbon nanotubes) are characterized by a high price, which affects the cost of information protection measures implemented using products based on such materials. In this regard, it seems relevant to search for low-cost conductive powder materials to create technical means of information protection from leakage through the channel of secondary electromagnetic radiation and inductions, as well as tools to reduce the radar visibility of ground objects.

# 1 MODERN METHODS OF ELECTROMAGNETIC SHIELDS MANUFACTURING ON THE BASIS OF POWDERED MATERIALS*

## 1.1 The Main Areas of Electromagnetic Shields Application

Electromagnetic shields consumers are industries such as electronics, energy, construction, medicine [1]. In electronics and communications, such products are used to protect elements, components, apparatus and equipment from interference fields of natural and man-made origin, and also like technical means of information protection. The use of technical means of electromagnetic waves shielding in environmental safety ensuring is a very important task to reduce the effects of electrical installations and equipment on the human body [2–4].

Figure 1.1 shows the main areas of electromagnetic shields application [5].

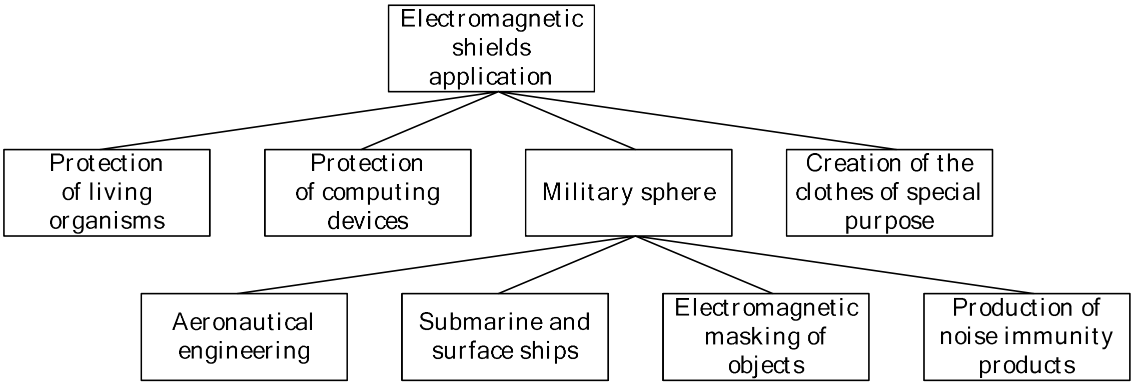

Figure 1.1 – The main areas of electromagnetic shields application

A typical scheme of the technical channel for information leakage is presented in Figure 1.2.

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* The chapter was written jointly with Tatiana Pulko.

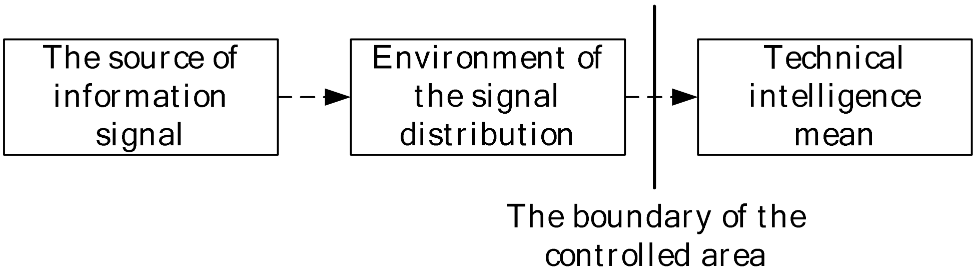


Figure 1.2 – The scheme of the technical channel for information leakage

In the paper [6] it was shown that the main principle of exposure to electronic equipment, leading to its inoperability, is a powerful electromagnetic effect. The result of such actions are violation of the operating modes of semiconductor devices, possible detonation of explosives (ammunition), impaired performance of sensor systems, electrical equipment of technical systems. The advantage of such weapons systems is the ability to transfer to a non-operational state special equipment without the use of radio reconnaissance information while maintaining the life of personnel [7].

The method of high-power pulsed microwave interference generating is based on the use of nuclear explosion simulators with a power of up to 40 mW. Another method of remote exposure to electronic equipment is the use of relivetic generators of microwave radiation, characterized by the possibility of spatial orientation and frequency-selective properties. The most vulnerable to microwave interference are various types of weapons controlled by radars, microwave receivers, radio channel signals, etc. The main means of protecting electronic devices from microwave interference include their shielding and the use of electronic systems that are insensitive to microwave radiation components.

Figure 1.3 shows the appearance of a microwave installation by Lockheed Martin and the American aircraft manufacturer Boeing, designed to locally disable electronics due to the direction of radiation of a powerful magnetron [8].

Figure 1.3 – The appearance of the installation with a pulse electromagnetic emitter CHAMP

In the United States, a test facility was created at Kirtland Air Base (Figure 1.4) to assess the effects of electromagnetic pulse simulators on various types of military equipment. The ways to improve this installation are determined [9].

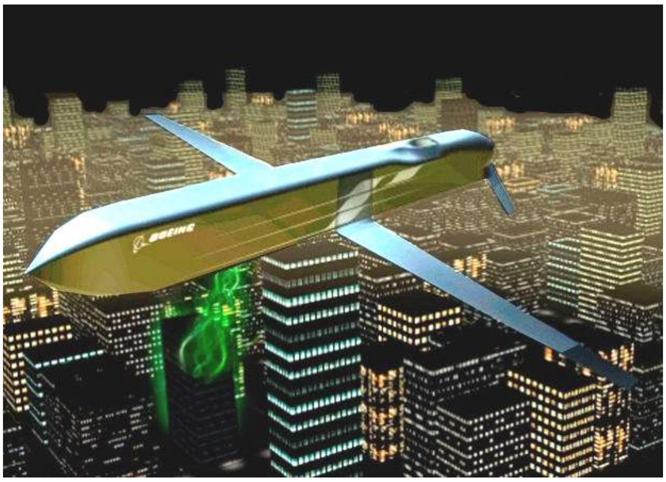


Figure 1.4 – Scheme of incapacitation of power supply of residential and special complexes

The main channels of selective destructive effects are the following:

- power supply system;
- wire lines;
- radio frequency channels [10].

In the paper [11] the history of electromagnetic weapons creation is described. The main theoretical ideas were published in the 1950s by the Soviet academician A.D. Sakharov. The first publications on the creation of shock-wave emitters of non-nuclear origin date back to 1984. Figure 1.5 shows the basic principle of their action [12, 13].

This design is a source of standing electromagnetic waves in the squib, the explosion of which translates these waves into traveling ones and develops tremendous impulse power due to the transition of the explosion energy into electromagnetic energy.

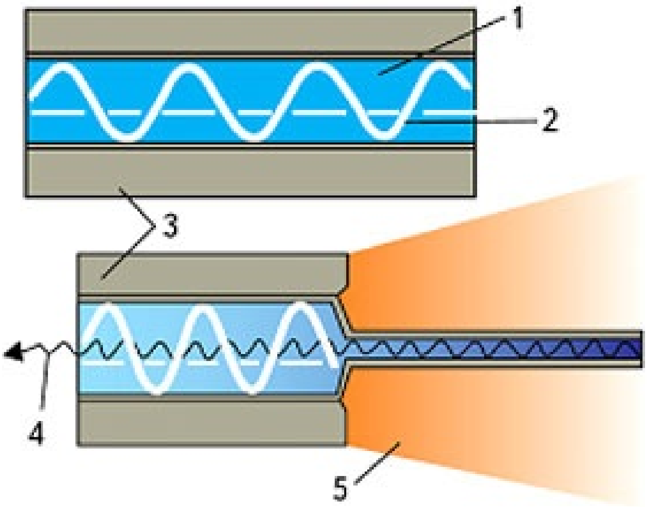


Figure 1.5 – The principle of operation of a shock wave emitter: 1 – electromagnetic resonator; 2 – standing wave; 3 – explosive; 4 – directional electromagnetic radiation; 5 – blasting products of the explosion

At the present stage, devices have been developed in which explosives are not used (range up to 1 km), characterized by wave beams with a power of up to 1 GW (Figure 1.6).

Figure 1.6 – The appearance of the technical means of electromagnetic terrorism

Table 1.1 shows the effects of ultrashort electromagnetic pulse generators on information systems.

Table 1.1 – The consequences of ultrashort electromagnetic pulses generators impact on information systems

| Information system type | Impact character | Consequences |
|---|---|---|
| Corporative network | A sequence of ultrashort pulses with an electric field strength at the point of impact of 2–10 kV/m; injection of a sequence of ultrashort electrical pulses into the power circuit and communication lines | Overload or failure of computers, resetting of BIOS settings, reducing the amount of information traffic |
| Navigation and communication means | Ultrashort pulses with electric field strength at the point of impact of 1.5–3.0 kV/m | Reduction in 2–10 times communication range, false readings or freezing of navigation equipment |
| Technical means | | Failure of readers and ACS controllers. False alarms of fire and security sensors. “Frozen frames” of digital TV cameras and webcams |

Table 1.2 describes the consequences of disruption in the operation of informatization tools in various industries.

The presented consequences cause the following:

– the need to create devices with a weakened sensitivity to electromagnetic influences;

– the need to create the development of more advanced methods of protection [14, 15].

Table 1.2 – Consequences of disruption in the operation of informatization tools in various industries

| Application areas | Possible consequences |
|---|---|
| Technological processes management | Initiation of beyond design basis accidents for the failure of technological equipment, stopping / slowing down technological processes |
| Monitoring and crisis management | Crisis out of control, inadequate management of the situation with unpredictable consequences |
| Banking infrastructure | Paralysis of banking activity, creation of conditions for unauthorized withdrawal of funds from bank accounts |
| Objects security | Creating the conditions for terrorist attacks, reducing the level of protection against natural and technological threats; false alarms in the absence of threats |
| Life supporting | Disruption of power supply to enterprises, initiation of accidents of power supply systems, creating uncomfortable conditions for personnel |
| Transport | Disruption of transport management and control; violation of the safety equipment on the railway; disruption of aircraft controls and navigation |

Electromagnetic shields are widely used to protect various military objects from their detection through technical leakage channels [16]. Such opposition to technical intelligence is one of the main ways to ensure engineering security. An example of such use is radar absorbing materials and coatings created on their basis, in ensuring a decrease in visibility (Stealth technology), from detection by radar [17]. The basis of this technology is the basic processes of absorption, scattering and interference of radio waves. In aeronautical engineering, elements of aircraft are made of various composite materials in the form of panels of six layers of ferromagnetic radio absorbers (F-117A "Lockhad") [18]. Moreover, these materials are used depending on the application in the form of paints, putties and coatings. F-117A (Figure 1.7) is made in the form of a pyramidal configuration for multiple re-reflection of the radar signals of the detection means.

Figure 1.7 – The appearance of F-117A

In the Russian Federation, at the Komsomolsk-on-Amur aircraft plant, the ninth test copy of the Sukhoi T-50 invisible fighter was launched for testing [19]. The first inconspicuous 2-pilot aircraft in this state is characterized by low cost (50 million US dollars) compared with the American F-35 (135 million US dollars), improved tactical and technical data. The industrial release of this equipment is expected from 2018. Equipping the T-50 with the Himalayas airborne jammer complex increases the degree of protection for this aircraft [20]. Similar systems are developed by US experts by setting all possible types of interference in an extended frequency range [21], which will make it difficult to operate the S-400 Triumph electronic devices (the best air defense system in the world).

The paper [22] describes the manufacturing technology of composite panels that absorb electromagnetic radiation (EMR) to reduce the visibility of aircraft and other military vehicles. The basis of this development is the use of charcoal powders and soft magnetic material in a high molecular weight or low molecular weight binder to increase mechanical strength. Figure 1.8 shows one of the variants of the compositional panel. In this panel, dielectric plating and a honeycomb structure are used, filled with 15 layers of high molecular weight films containing the above powders. The author suggests using silicone rubber as a filler in one of the designs. The particle sizes of carbonyl iron and charcoal are less than 20 microns. The frequency characteristics of the electromagnetic radiation transmission and reflection coefficients are not presented in the work.

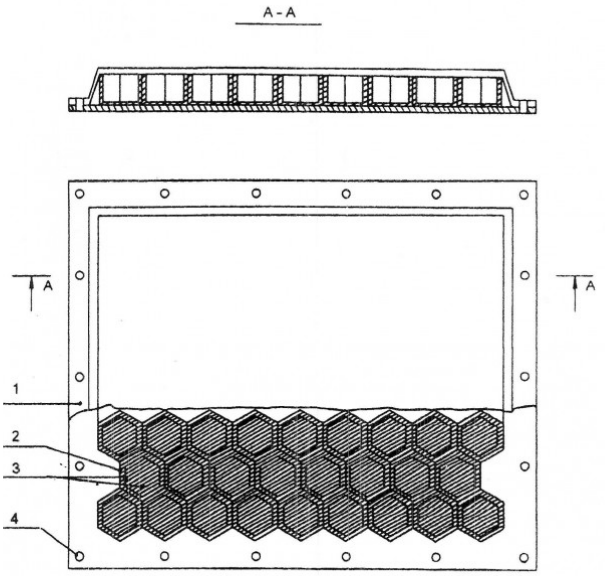


Figure 1.8 – Compositional panel

The main problem of protecting objects from detection by automated technical reconnaissance and guidance of high-precision weapons (missiles, guided ammunition, etc.) is the significant area of these structures and the impossibility of their long-term concealment [23, 24]. To organize counteraction to such systems induced by reflected radar signals, inclined masks and radar absorbing mask designs, various radar angle reflectors and terrain [25] are used. It is shown that the integration of the above means of protection by the construction system of false targets, aerosol masking and the use of electronic warfare systems in a single complex creates the possibility of increasing their survival in extreme conditions. At the same time, the creation of low-cost electromagnetic screens with a size of more than a dozen square meters seems to be the main problem.

The search for means of protecting the body from electromagnetic radiation of anthropogenic nature seems to be a very important and timely problem [26–28]. An increasing number of telecommunications, medical diagnostics, transport control, access control, consumer electronics increases the level of electromagnetic effects on living organisms and their environment, affects the structure of cells, which leads to their possible temporary modification. It was shown in [29, 30] that the use of water-soluble fillers in various environments (cellulose, fabric, knitwear, chopped wood, highly porous powders, etc.) allows the creation of electromagnetic screens for various fields of application. To protect the premises, various radio shielding paints and concrete are widely used [31, 32]. A reduction in the EMR level is achieved up to 40 dB. EMR shielding fabrics and curtains of various composition and structure are offered by light industry enterprises. In their composition they contain thin threads of silver, copper, steel and their alloys. The finest metal mesh in such tissues is a means of EMR attenuating to 60 dB at a frequency of 1 GHz. A variety of shielding clothing is being developed [33] based on the above-described canvases in the form of shirts, trousers, sweaters and suits.

## 1.2 Basic Powder Materials forCreation of Composite Constructions of Electromagnetic Shields

At the present stage of engineering and technology development, a sufficiently large number of materials and shielding constructions based on them have been developed. In addition to the set (planned) level of EMP interaction characteristics, the main properties of such materials are operational parameters: temporary stability, the possibility of operation both in open and closed spaces, dependence on operating temperature, chemical resistance, atmospheric pressure, weather conditions and much more [34].

The main components of composite materials for electromagnetic shields are various powder materials to ensure absorption and dispersion of electromagnetic energy [35].

Traditionally used materials include rolled products and foils of various metals (steel, aluminum, lead, copper, etc.), powder materials (carbons, metals, dielectrics, ferrites), fibers and nets (carbon fabrics, filamentary wire samples, micro and macro spheres) Powders are usually placed in various polymer binders (polyethylene, polypropylene, copolymers). The choice of such materials is determined by the operating conditions [36, 37]. The placement of these materials in the composition of paints allows the formation of various types of coatings for their use in electromagnetic shields [38, 39].

The rapid development of nanotechnology and the production of various nanomaterials significantly expanded the range of materials and composites based on them to create new materials used for electromagnetic shields production. Methods of chemical, electrochemical, vacuum deposition of thin and thick films (thick-film technology) allow the formation of magnetic, conductive, dielectric coatings on various substrates [40, 41]. Depending on the thickness, shape and electrical characteristics, these processes also represent a great prospect for providing the required properties of electromagnetic shields.

The creation of specific constructions of electromagnetic shields is based on the transition of wave characteristics from the propagation medium in space (air, vacuum) to the shield material. This is usually realized by changing (increasing) the density of subsequent layers of material. The increase in the active surface is realized due to the geometric shape of the material facing to the radio emissions source. For these purposes, they increase the level of their porosity, create pyramidal shapes, conical structures. Figure 1.9 shows samples of radio absorbers made of pyramid-type materials. Typically, the slope of the pyramid-shaped faces is an angle of about 12.5°. One of the most significant characteristics is their broadband frequency properties in terms of EMR attenuation in the required frequency ranges of application.

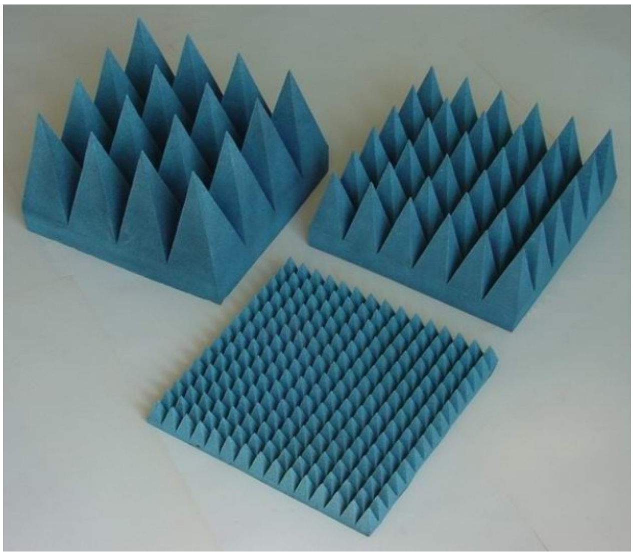


Figure 1.9 – The radio absorbers of pyramid-type

The radio absorbing constructions of electromagnetic shields of resonant type are characterized by the neutralization of radiation due to their thickness (3/4 of the radiation length) - the Jauman design [42]. The construction of the Salisbury shield up to 10 mm thick is made of variable-capacity semiconductor materials embedded in a coating placed on metal cases. A schematic illustration of the construction of such shield, operating in the frequency range 0.7–2 GHz [43], is presented in Figure 1.10.

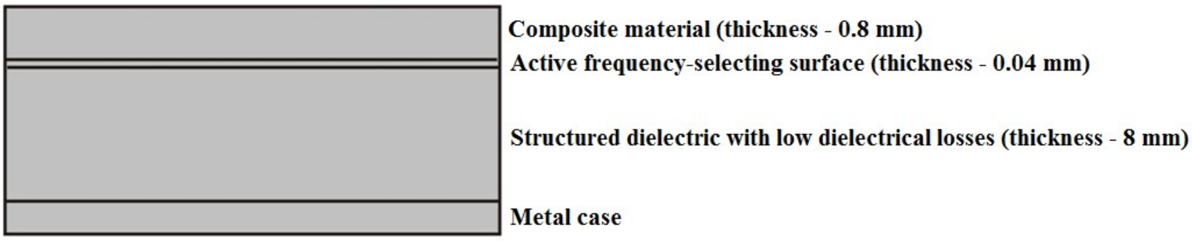


Figure 1.10 – Stratified composition of the “Salisbury” type shield

A set of works aimed at substantiating the use of aqueous media selectively placed in various materials for use as radio absorbing and radio reflecting components of EMR shields was carried out at the Belarusian State University of Informatics and Radio Electronics [44, 45]. A feature of such shields is the use of aqueous media introduced into various insulating matrices (woven, knitted and needle-punched fabrics, powders, film insulating materials, foamed microporous and nanoporous materials and structures) [46–52].

It was shown that water-containing cellulose impregnation can reduce to –60 dB electromagnetic impulse exposure at a frequency of 37 GHz [53]. Introduction to aqueous solutions up to 50 vol. % of calcium and magnesium salts allows to stabilize the content of the water component in such matrices [54] during storage and operation of electromagnetic shields based on them.

## 1.3 Carbon-Containing Materials for Electromagnetic Shields

At the present, there is a wide variety of materials in various forms used as electromagnetic shields. Depending on the functional purpose, to ensure the required characteristics of EMR reflection and attenuation, it is necessary to fix permanently such shields, which is determined by the mounting method and the shape stability of the structure [55]. Figure 1.11 shows the classification of modern shielding materials. An analysis of this classification indicates that shields based on composite materials are characterized by the possibility of creating the most diverse combinations of their composition and the variety of constructive manufacturing. The main advantage of metal shields is its high conductivity, but their corrosion and temperature resistance, compared with carbon materials, is not stable enough.

According to the presented classification, homogeneous carbon shielding materials, which are characterized by conductive properties, can be used in the form of bulk structures made of powders, pressed materials. Such materials include technical carbon (soot), graphite, graphene, etc.

Shungites (30 % carbon) and taurites (10 % carbon) are natural heterogeneous composite materials [56]. Homogeneous filling structures, as a rule, are solid-state plastic structures filled with such materials in the form of powders, including a pyramid-shaped one, which limits their use.

Carbon nanotubes are synthesized in the form of single-walled and multi-walled structures and are usually used in the form of composites, however, their production at this stage presents certain technological difficulties (process temperature, the need for selective selection) [57].

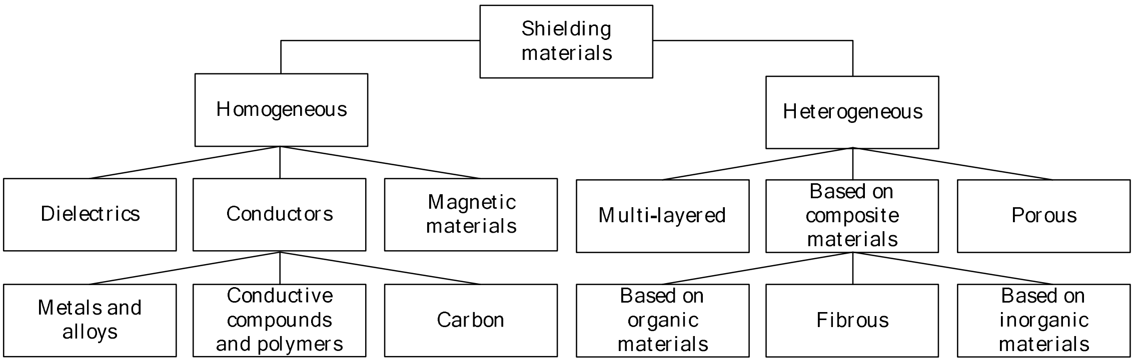


Рисунок 1.11 – Classification of shielding materials [55]

Promising materials for electromagnetic shielding are carbon fibers with a threadlike configuration up to 15 microns thick, consisting of crystals based on carbon atoms [58]. Composites from such materials are stable when used in aggressive environments and at temperatures up to 350 °C in air. The use of carbon fibers and ceramic binders allows to create of composites suitable for use at higher temperatures. In the manufacture of modern flying devices of carbon fibers, up to 30 tons are used per product (Boeing company).

Based on these fibers, a wide range of heating elements (heating clothes, shoes, processing equipment), respiratory protection, blood purification, and pharmacology are made. Automotive and sports goods production spheres are also an active consumers of carbon fibers [59]. Basically, such fibers are made from polyacrylonitrile materials (at the present stage), viscose.

Figures 1.12 and 1.13 respectively show the appearance of graphite and activated fibers made from viscose. These materials are characterized by high porosity, low strength and good heat-insulating sorption properties. On the basis of such fibers, a sufficiently large range of materials is obtained for use as electromagnetic shields [60–62].

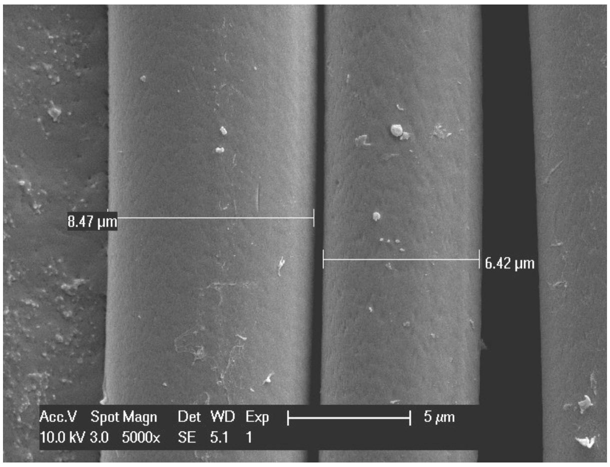


Figure 1.12 – Appearance of graphitized carbon fiber from viscose (increased to 5 thousand times)

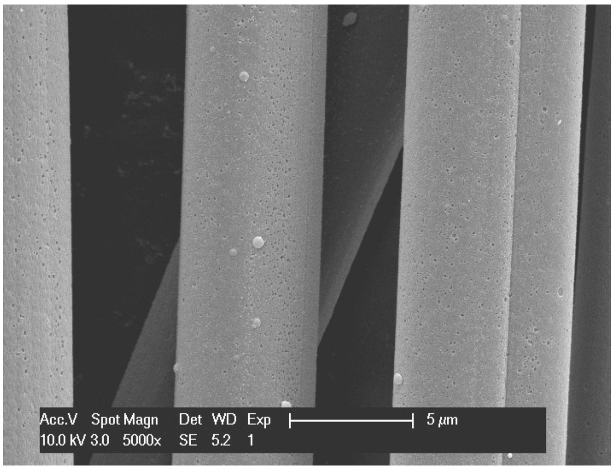


Figure 1.13 – Appearance of activated carbon fiber from viscose (increased to 5 thousand times)

It was shown in papers [63, 64] that to reduce the radar visibility of a marine vessel, its hull is made of carbon fiber based on bundles of carbon fibers up to 1 cm thick and consisting of 12–24 thousand individual fibers. The peculiarity of the harnesses is that the threads are twisted at different angles for additional dispersion of the radar signals. Architectural protection and the use of the above materials can reduce the effective reflective surface of a marine vessel up to 10 times [65].

In the Russian Federation, the leader in the creation of carbon black nanocomposites is the Institute of Hydrocarbon Processing Problems of the Siberian Branch of the RAS (Omsk) [66]. The matrix synthesis method proposed by scientists made it possible to create the technology of granular carbon, carbon nanocomposites based on pyrolytic and carbon black with controlled (depending on the synthesis conditions) porosity of such materials (technosob, sibunit) [67]. These materials are promising for use not only for chemical systems for the production and storage of electricity, but also for the manufacture of electromagnetic shields.

A method of ion bombardment of a carbon PAN fiber for corrugating its surface with a height and period of 0.5…1 µm was proposed in [68, 69]. The fibers are formed by argon ions at a temperature of 250 °C (energy 30 keV). The specific surface of the fibers increased from 0.5…1.5 to 107 $m^2/g$ while maintaining the strength characteristics.

Such fibrous composite materials are highly effective for use at elevated temperatures when placed in polymer and ceramic matrices.

Electrically conductive fillers placed in paints and varnishes made of carbon-containing materials (carbon black, carbon fiber, graphite, etc.) are very promising for creating coatings of various electromagnetic shield constructions with stable properties [70].

As shown in [71], the including of various carbon-containing materials (fullerenes, carbon fibers, nanowires, carbon nanotubes) into various polymer and ceramic matrices with controlled layer-by-layer concentration allows to create electromagnetic shields with different EMR attenuation and reflection characteristics.

The following is an analysis of the use of polymeric materials as a reinforcing material (matrix). The possibility of their application to create electromagnetic shields, regardless of their variety and composition is shown in papers [72, 73].

In order to create composite coatings for electromagnetic shields based on powder paints, preliminary processing of functional additives to paints (carbon powders, steels) in ball mills is proposed. This technology allows to obtain more reproducible frequency dependences of EMR attenuation and reflection of such coatings, when these additives are added to paints [74].

The results of the study of electromagnetic shields based on carbon fillers and ferrite powders with a hexagonal structure for use as protection against the harmful effects of cell phones are presented in papers [75, 76]. The multilayer design of such shield is a layer of silicone filled with ferrite powder placed on the surface of a polymer composite with a high concentration of carbon nanostructures. With a screen thickness of 2.5 mm, the EMR attenuation value is from 3 to 10 dB in the frequency ranges of GSM networks.

When shielding EMR in the working area of a marine vessel, the authors of the paper [77] proposed the constructions of electromagnetic shields based on foam glass materials with carbon impurities, characterized by acid resistance, operating temperature range from –260 to 500 °C. The reflectivity of such materials was up to 0.97 (reflection coefficient) in the frequency range 1.45–78 GHz. However, the authors do not give the frequency dependence of EMR reflection coefficient.

It seems very promising to obtain modified carbon materials of the sibunit family [78]. Their manufacture is as follows:

– granulation of dispersed carbon black in aqueous solutions of organic compounds;

– deposition of pyrolytic carbon from gaseous media (temperature 700…1100 °C);

– heat treatment at temperatures up to 950 °C for local removal of reactive sections of the composite to create porous structures (pore size 18…300 nm).

The creation of graphene-coated lenses for not only vision correction systems, but also for electromagnetic shields [79] due to the preservation of moisture on the surface of the cornea seems to be original. The methodology for their manufacture is not published.

The strong and elastic structure of the absorbent “graphene layer – dielectric layer – graphene layer” is proposed for shielding the human body from electromagnetic effects. The main disadvantage of this material is the need for its electrical grounding [80].

The use of carbon-containing nanocomposites by modifying polymer materials (epoxy resin, latex) made it possible to establish a value of up to 2 masses. %, which does not lead to the degradation of the components used and the change in their thermal properties [81]. In this work, it is shown that an increase in the concentration of nanocomposites (for example, carbon nanotubes) to 2 % leads to an increase in reflectivity. The thickness of the composite was up to 0.4 mm, which significantly reduces its cost.

According to the publication [82], a group of researchers proposed the design of an EMR absorber based on the deposition of graphene layers from the gas phase and their subsequent deposition on a layer of organic acrylic glass. The maximum EMR absorption value was observed on a 6-layer graphene coating. The main disadvantage of such structures is the need to isolate them from the external chemical and temperature environment.

The results of the study of the radio-absorbing properties of composites based on micro-sized fillers (graphite and carbon black) and nanotubes in epoxy binders are presented in [83, 84]. It is shown that nanocomposites have the same absorbing and reflecting characteristics compared to materials based on carbon black in the frequency range 52…73 GHz.

Carbon-containing fibers are filamentary structures (filament diameter up to 15 μm), mainly consisting of carbon atoms. Such fibers have chemical inertness, low specific gravity and high mechanical strength [85]. The main method of their formation is the heat treatment of natural (cotton, cellulose) and chemical (e.g. polyacrylonitrile) fibers at temperatures up to 3000 °C in an inert atmosphere. Currently, different types of products are produced: threads, fabrics, powders (grinding threads). Such materials are used to create carbon fiber reinforced plastics (aircraft, automotive, etc.), electric heaters, environmental protection, and pharmacology. Electromagnetic shields based on them are characterized by low weight. Based on them, products with high mechanical strength and stability of properties over time can be made.

Figure 1.14 shows the appearance and description of the layers of a four-layer composite radio absorbing material.

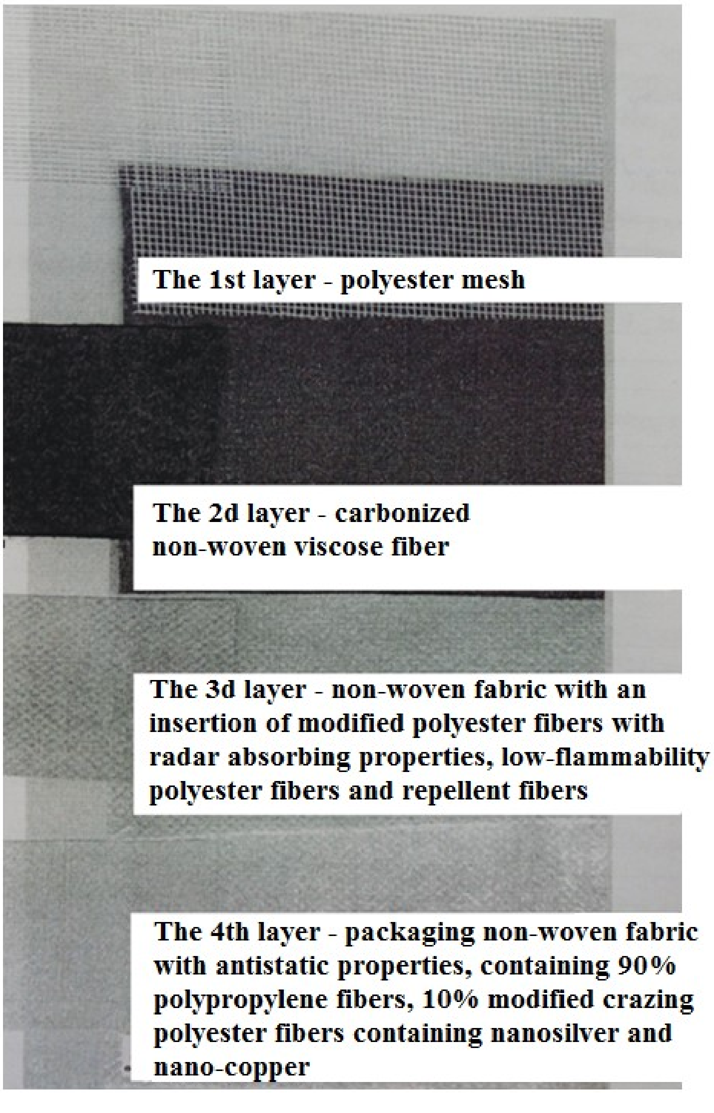


Figure 1.14 – The appearance and description of the four-layer composite radio absorbing material

Table 1.3 shows EMR attenuation values of the Voskhod brand tissues [86].

Table 1.3 – EMR attenuation values of the Voskhod brand tissues

| Radiation frequency, GHz | EMR attenuation value, dB | | | |
|---|---|---|---|---|
| | V-1 | «Voskhod-1N» | «Voskhod-YN» | «Voskhod-12NM» |
| 37.5 | 20 | – | – | – |
| 9.3 | 28 | – | 70 | 70 |
| 3.0 | 40 | – | 70 | 70 |
| 1.2 | 43 | 40 | 81 | 99 |
| 0.6 | 46 | 44 | 75 | 98 |
| 0.3 | 54 | 47 | 70 | 99 |

# 2 RESEARCH METHODOLOGY

## 2.1 Justification for Use of Coal-Based Powders as a Component for Electromagnetic Shields

Coals has been used to ensure the life of the planet's population for quite some time (the first records date back to the 4th millennium BC). The carbon content in charcoal is about 85 %. The remaining components are oxygen, phosphorus, hydrogen, volatiles, ash, moisture [87–89].

Currently, the following methods of coals using are known [90]:

– in electronic materials science – in the process of pure silicon production;

– in non-ferrous metallurgy – for the production of aluminum and boron;

– in printing and instrument-making – for polishing parts and forms;

– in the chemical industry – for the production of smoky powders, electro-carbon components, fillers of various plastics, household fuels, lubricants, food additives.

Figure 2.1 provides information on the main types of charcoals currently produced.

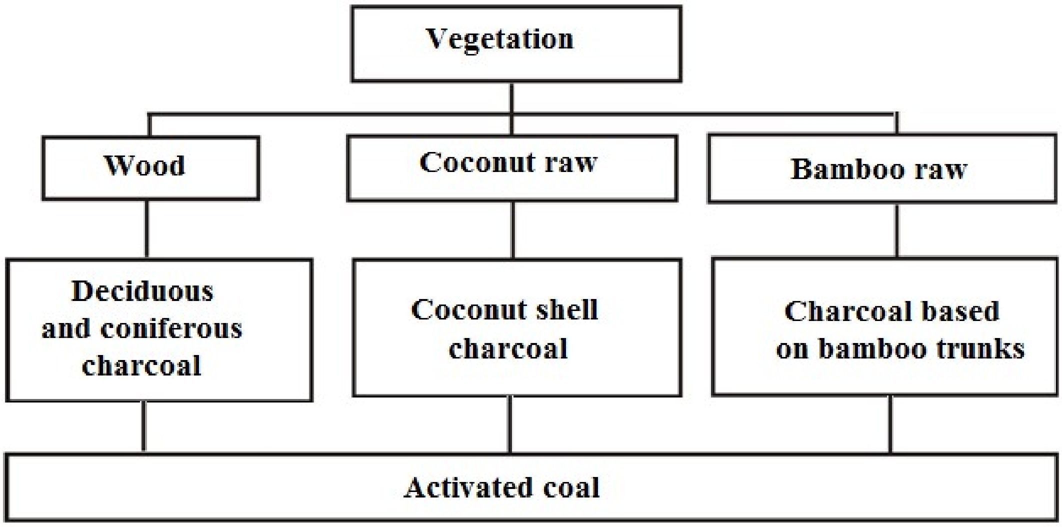


Figure 2.1 – The main types of coals

Obtaining charcoal is realized by heating vegetation (wood, coconut or bamboo raw materials) without air access in special furnaces or retorts [91].

### 2.1.1 Wood Based Coal

Figure 2.2 shows the appearance of coal obtained on the basis of wood, Figure 2.3 is a micrograph of its surface [92].The specific porosity of 1 g of such coal is 160–400 m$^2$.

Figure 2.2 – The appearance of the coal samples

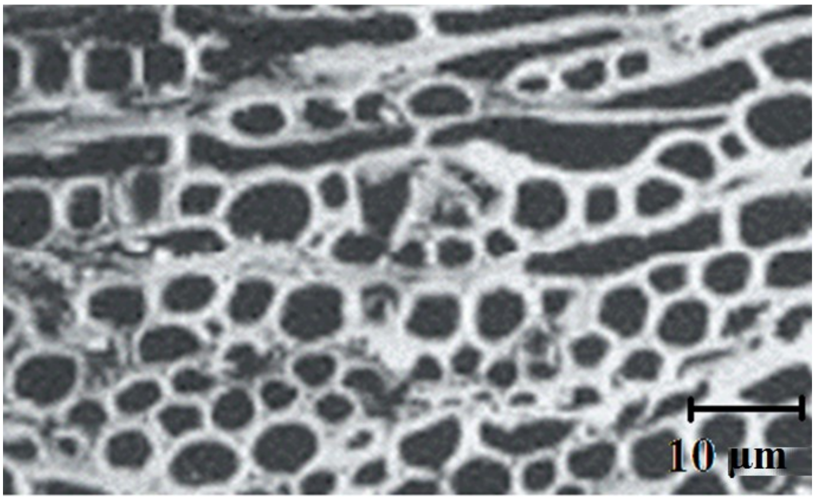


Figure 2.3 – Charcoal surface micrograph

The mass of 1 m$^3$ of coal on the basis of spruce wood is up to 120 kg, on the basis of pine wood – up to 140 kg, on the basis of birch wood – up to 180 kg, on the basis of beech wood – up to 190 kg. The volume of pore space to the volume of the base of coal is 70–80 %. The cost of 1 kg of wood-based coal does not exceed 2 US dollars.

### 2.1.2 Activated Coal

Activated coal is characterized by a significant specific surface area per unit mass (up to 1500 m$^2$ per 1 g of mass), which is associated with its high porosity (Figure 2.4).

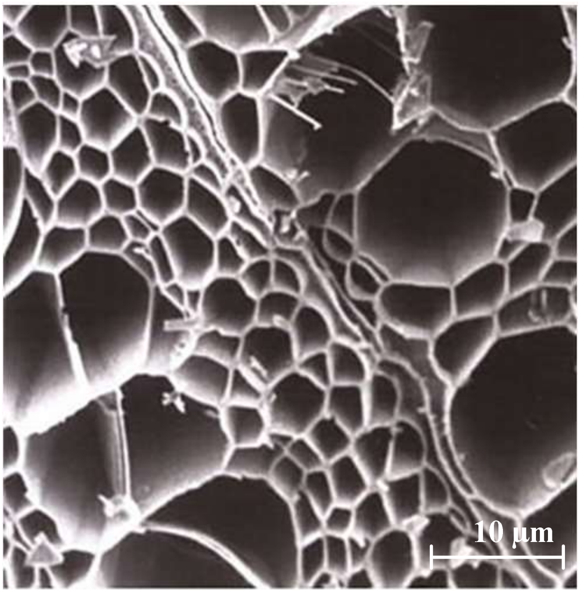


Figure 2.4. – Activated charcoal surface micrograph

The main raw material base for activated coal is carbon-containing materials of natural origin (wood, coconut shell). The process of production of activated coal consists in charring these materials and their subsequent activation, which, as a rule, is carried out by heating in an environment based on an activating reagent [93].

The specific surface and pore size of activated coal depend on the production conditions and the type of coal-containing material used to produce it. The pore size of activated coal obtained from a coconut shell is up to 2 nm (Figure 2.5), from wood – from tens of nanometers to units of micrometers.

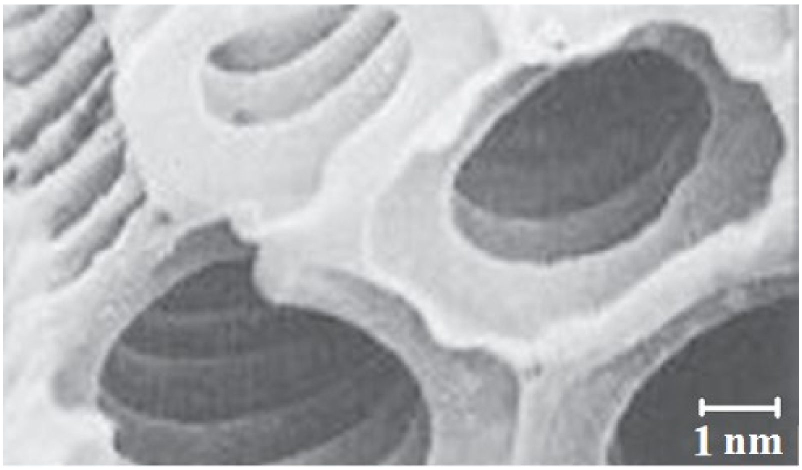


Figure 2.4. – Activated coconut shell surface micrograph

Activated coal is widely used in pharmacology, as well as for the purification of water and electrolytes, the manufacture of gas masks, the production of sugars, and the preparation of composts. Activated coal based on coconut shells is an effective absorber of emanations of radioactive elements (radium, thorium) [94]. The cost of 1 kg of activated carbon in the growing regions of the materials used for its production is about 2 US dollars.

The widespread and low cost of wood-based coals make them promising as a base material for electromagnetic shields [95].

## 2.2 X-Ray Analysis Methodology

The analysis of the chemical composition of the powder materials used in the framework of this work was carried out using x-ray phase analysis. The characteristics of the diffraction patterns were obtained using the DRON-3M setup. To do this, the test material was mixed with a small amount of radiolucent adhesive and applied to a glass plate.

The chemical composition of the substance was determined using the program Crystal Impact MATCH! v. 1.11. The program's principle of operation is based on comparing the analyzed diffractogram with the reference diffractograms of substances stored in the Crystallography Open Database (COD). The phases of a substance in a material are identified if no less than three X-ray diffraction maxima coincide for the analyzed and reference diffractograms.

### 2.3 Conductivity Assessment Methodology for Powdered Coal-Containing Materials

The conductivity ($G$) of powdered coal-containing materials was estimated using an instrumental and calculation method based on the implementation of the following steps.

*Step* 1. Filling with a coal-containing powdered material of the cell, characterized by a rectangular section and a useful volume of 0.75 cm$^3$. A schematic representation of the cross section of the cell is shown in Figure 2.6.

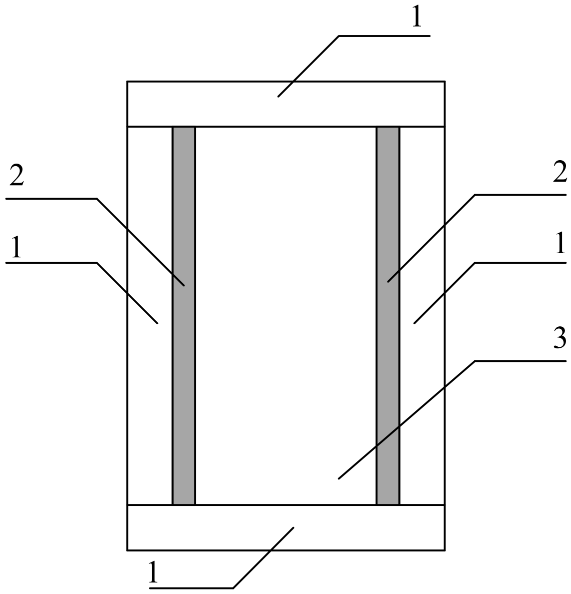


Figure 2.6 – Schematic representation of the cross section of the cell used to fill with coal-containing powder material: 1 – cell walls made of organic glass; 2 – electrodes made of stainless steel; 3 – useful volume of the cell

*Step 2.* Connecting to the electrodes of the cell filled with coal-containing powder material, the immitance meter E7-20.

*Step* 3. Defining of resistance (*R*) of coal-containing powder material placed in a cell using E7-20 immitance meter. The frequency range is from 50 Hz to 1 MHz, the amplitude of the measuring signal is 1 V.

*Step* 4. Calculation of *G* value using the formula $G = \frac{l}{R \cdot S}, \text{Sm/m}$, where *l* – distance between cell electrodes, m; *S* – electrodes area, m$^2$ [96].

## 2.4 Assessment Methodology of Electromagnetic Radiation Transmission and Reflections Coefficients of Shield Constructions

The values of the EMR attenuation (*A*) and the standing wave ratio (VSWR) in the frequency range of 8.0–12.0 GHz of the studied samples were measured using a panoramic attenuation and VSWR meter Ya2R–67 with sweep generator and waveguide path, which provides the detection of the levels of incident, reflected, and transmitted electromagnetic waves. Calibration of the specified equipment was performed according to the standard method. The characteristics of the setup used to measure the EMR attenuation and VSWR of the samples are presented in Table 2.3.

Table 2.3 – The characteristics of the setup used to measure the EMR attenuation and VSWR of the samples

| | |
|---|---|
| Attenuation measurement range, dB | –35.0…0 |
| Attenuation measurement error, dB | ±(0,5+0,05A) |
| VSWR measurement range | 1.06…5.0 |
| VSWR measurement error, %<br>– in values range 1,2…2,0<br>– in values range 2,0…5,0 | ±(5·VSWR+2)<br>$\frac{\pm(5 \cdot \text{VSWR} + 2)}{100 - [\pm(5 \cdot \text{VSWR} + 2)]\frac{\text{VSWR}}{\text{VSWR} + 1}} \cdot 100$ |

For the measurements conducting the used equipment was connected in accordance the schemes presented in Figure 2.7.

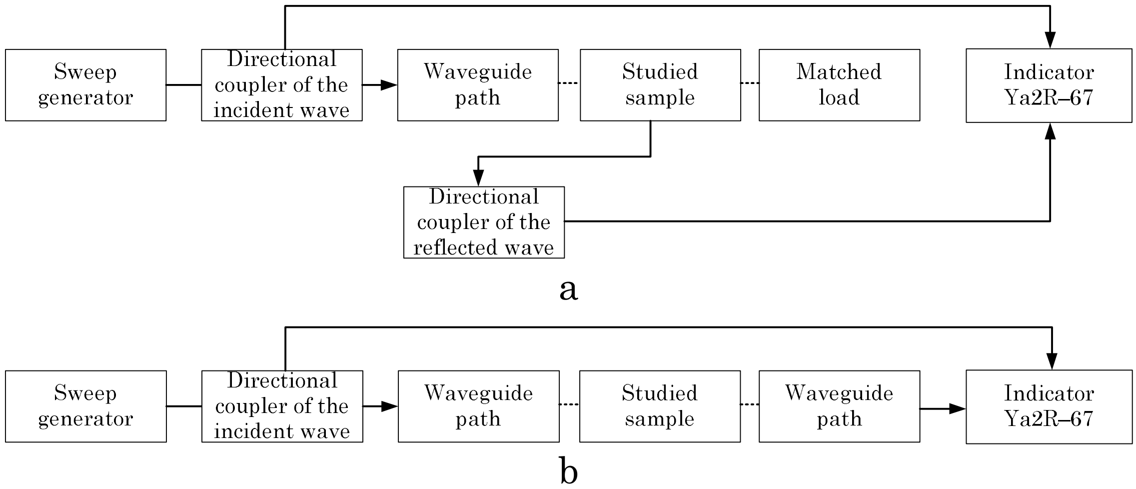
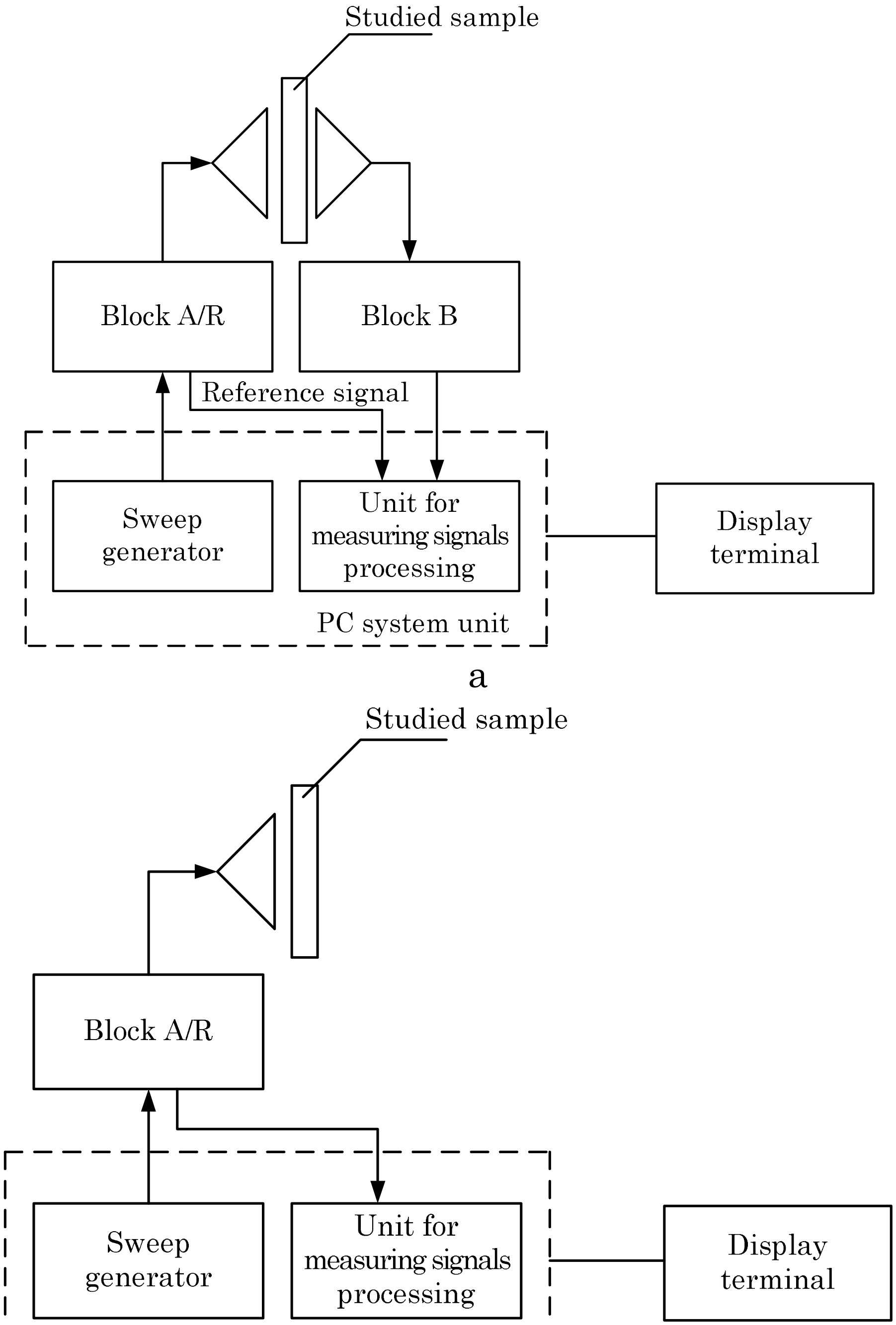


Figure 2.7 – The schemes of equipment connecting for measuring of EMR attenuation (a) and VSWR (b) in frequency range 8.0–12.0 GHz of the samples

Based on the measurement results of the EMR attenuation and VSWR of the samples, the values of EMR transmission ($S_{21}$) and reflection ($S_{11}$) coefficients of the latter were calculated. The following formulas were used: $S_{21} = -A$, dB; $S_{11} = 20\lg\left(\frac{\text{VSWR}-1}{\text{VSWR}+1}\right)$, dB.

EMR transmission and reflection coefficients shields in the frequency range 0.7–17.0 GHz were determined using a panoramic meter transmission and reflection coefficients SNA 0.01–18, operating on the principle of separation and direct detection of the levels of incident and reflected waves. The panoramic meter includes sweep generator, unit for measuring signals processing, transmitting and receiving horn antennas P6-23M, blocks of directional couplers (blocks B and A/R), designed to isolate and detect incident, reflected and transmitted electromagnetic waves and connected to the channels of the measuring signal processing unit and antennas.

For the measurements conducting the panoramic meter equipment was connected in accordance the schemes presented in Figure 2.8. The relative error of measurements made using the setup is ± 1%.



a

b

Figure 2.8 – The schemes of equipment connecting for measuring of EMR transmission (a) and reflection (b) coefficients in frequency range 0.7–17.0 GHz of the samples

Measurements were performed in automatic mode. To set the initial measurement parameters (frequency range, type of the measured parameter) and systematize its results, special software was used. The processes of the sample EMR reflection and transmission coefficients values measuring were preceded by calibration of the panoramic meter. The purpose of the calibration is to establish the optimal power level for the operation of the panoramic meter detectors.

For the calibration conducting the panoramic meter equipment was connected in accordance the schemes presented in Figure 2.9.

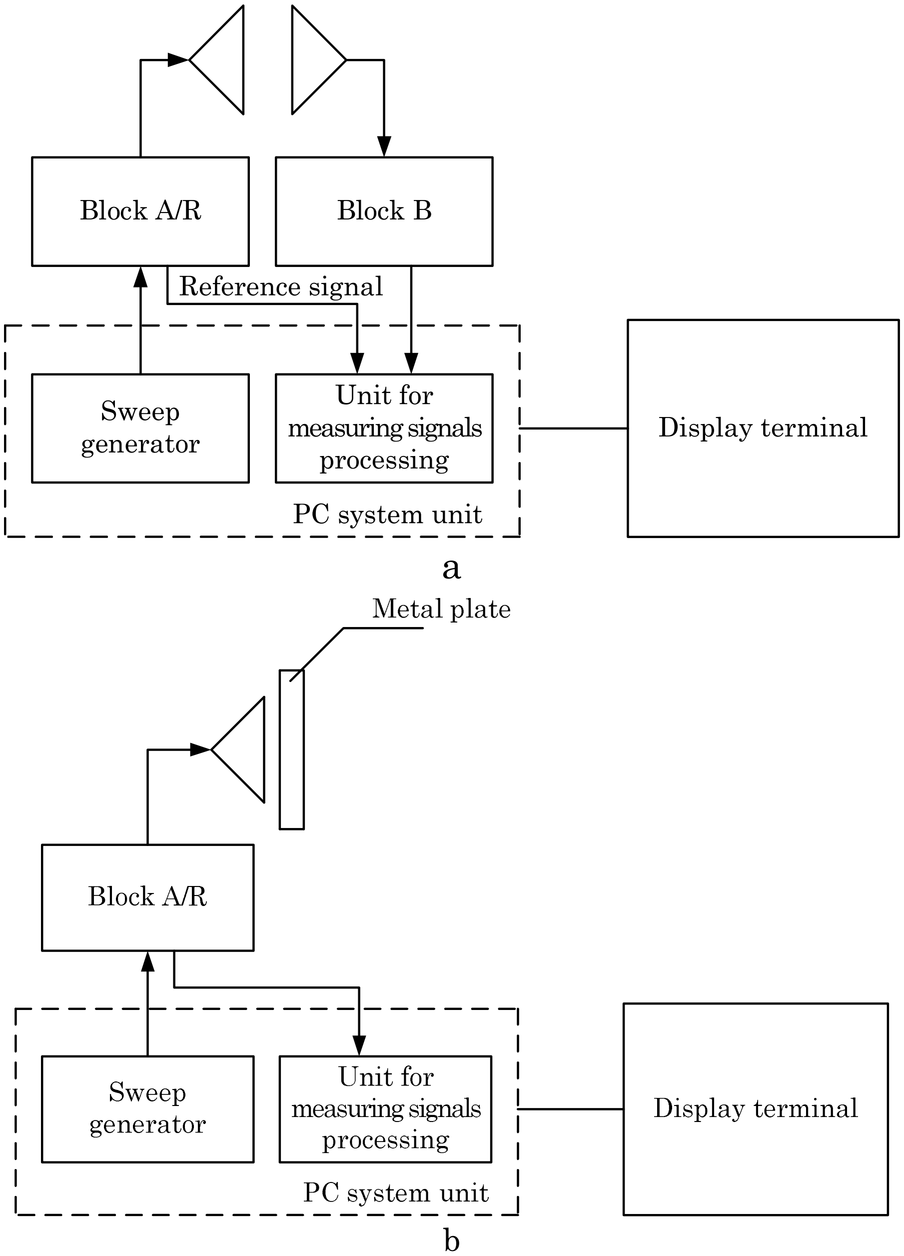


Figure 2.9 – The schemes of equipment connecting the calibration conducting before measurement of EMR transmission (a) and reflection (b) coefficients

## 2.5 Methodology for Studying the Process of Electromagnetic Shields Structural Elements Interaction with an Open Flame

Studies of the electromagnetic shields structural elements interaction with an open flame were carried out in accordance with the Fire Safety Standards. To do this, these samples of 220×170 mm in size were fixed in a vertical position, after which an open flame was applied to their surface. The open flame source was a portable gas-air technical burner PALIR (EUROGAS). The distance from the nozzle of the burner to the surface of the sample was 17 mm, the flame height with a vertical arrangement of the burner was 40±2 mm, and the flame temperature was 1700 °C.

During the study, thermograms of the studied samples were recorded in the middle and far infrared ranges, and the process of changing their appearance was documented. In this case, an IRTIS-2000 CH thermal imager was used.

According to the results of the study, it was determined what type the material on the basis of which the electromagnetic shield construction element is made belongs to: combustible, slow-burning, or low-flammable.

## 2.6 Methodology for Studying the Influence of Coal-Containing Materials on the Radius of the Controlled Zone of the Secondary Electromagnetic Radiation of Computer Equipment

During the studying the influence of coal-containing materials on the radius of the controlled zone of the secondary electromagnetic radiation (SEMR) of computer equipment the computer equipment with the following parameters was used:

– motherboard Intel DB43LD;

– central processor Intel Dual Core E5400 (clock frequency – 2.7 GHz);

– Hynix DDR2 random access memory (clock frequency – 800 MHz);

– Western Digital WD2500AAKX hard drive (SATA).

The study included three stages.

At the first stage, measurements of SEMR intensity of the computer equipment system unit located in an unshielded room ($e_0$), and the intensity of the electromagnetic background in this room ($e_n$). Table 2.4 shows the frequencies ($f$), at which SEMR intensity of the studied computer equipment over the intensity of the electromagnetic background in the room where it is located, as well as the indicated parameters values.

Table 2.4 – Values of SEMR intensity of the investigated computer equipment system unit and the intensity electromagnetic field in the room in which the measurements were made

| $f$, MHz | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 |
|---|---|---|---|---|---|---|---|---|---|---|
| $e_0$, dBmV/m | 9,26 | 13,86 | 20,19 | 13,43 | 16,02 | 15,96 | 15,67 | 11,79 | 14,95 | 12,94 |
| $e_n$, dBmV/m | 8,05 | 11,50 | 8,34 | 8,34 | 10,64 | 8,48 | 7,48 | 6,76 | 6,76 | 6,76 |

At the second stage, the values of the SEMR intensity of the computer equipment system unit shielded by a coal-based covering material were measured.

At the third stage, using the obtained measurement results, the radius of the controlled zone of SEMR of the investigated of the computer equipment system unit was calculated according to the algorithm presented in [97].

# 3 COAL-CONTAINING MATERIALS FOR ELECTROMAGNETIC RADIATION SHIELDING*

## 3.1 Electromagnetic Radiation Reflection and Transmission Characteristics of Charcoal

To study EMR reflection and transmission characteristics in the frequency range 0.7–17.0 GHz of charcoal, the authors made the construction consisting of a sheet of drywall 1 cm thick, on the surface of which charcoal pieces with a size of 1–5 cm were fixed by adhesive composition. The appearance of such construction is shown in Figure 3.1.

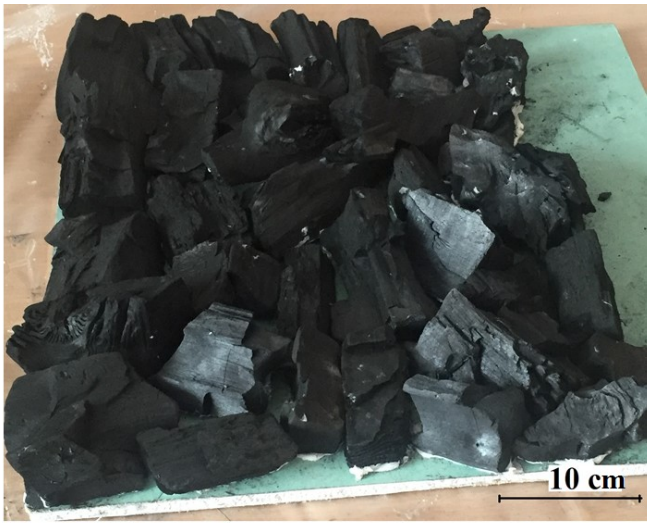


Figure 3.1 – Appearance of construction based on charcoal pieces and drywall

Figure 3.2 shows the frequency dependence of EMR transmission coefficient in the range of 0.7–17.0 GHz of the presented construction. It was established that EMR

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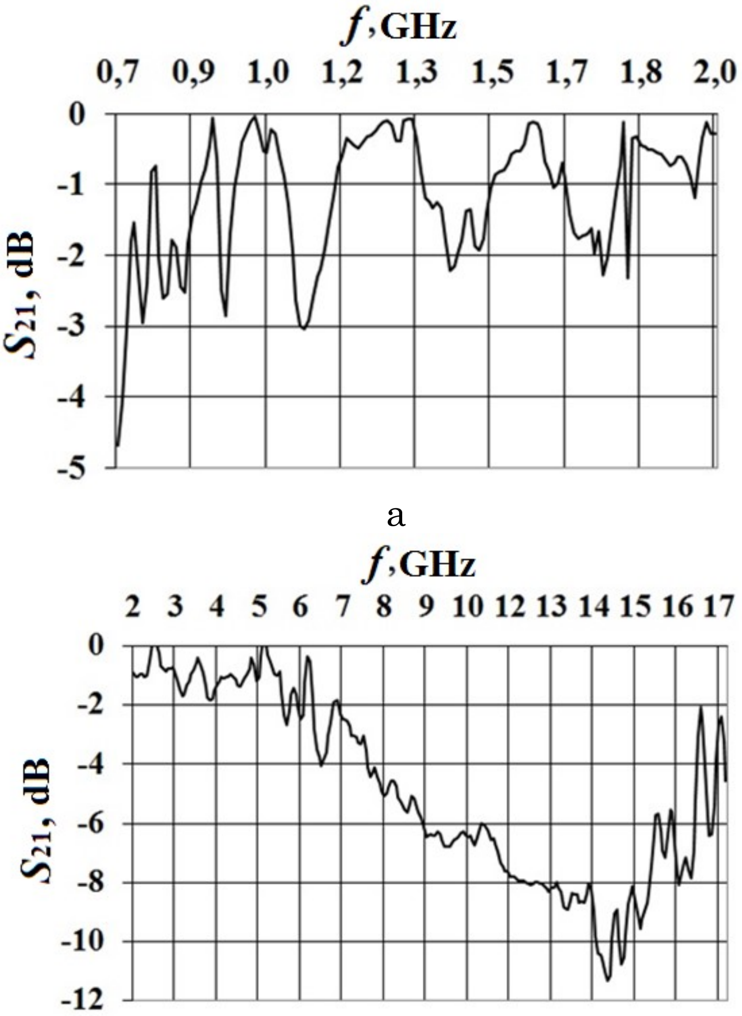
* The chapter was written jointly with Tatiana Pulko.

transmission coefficient values ($S_{21}$) of the construction vary from –1.0 to –2.0 dB in the frequency range 0.7–6.0 GHz and from –2.0 to –11.0 dB in the frequency range 6.0–17.0 GHz. The frequency dependence of the EMR transmission coefficient in the range of 2–17 GHz of the considered construction is a resonance curve asymmetric with respect to the center frequency, whose value is 14.0 GHz. The resonance of EMR reflection characteristic of the construction is due to the mutual compensation of the energy of electromagnetic waves of a specified frequency reflected or scattered by the construction surface.

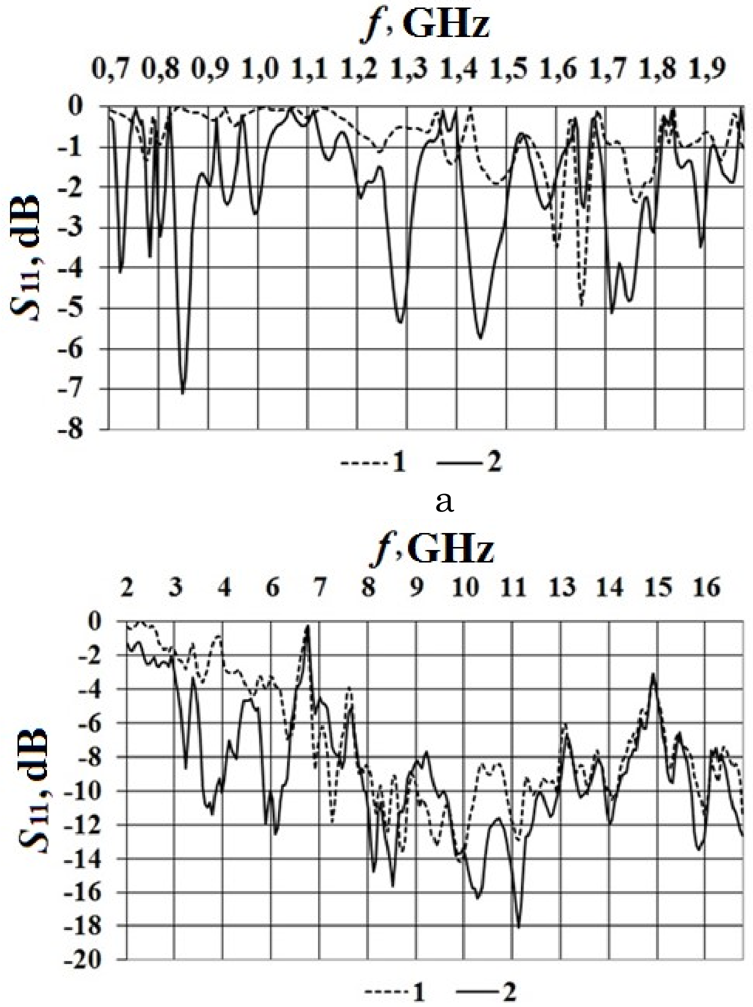


a

b

Figure 3.2 – Frequency dependences of EMR transmission coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of the construction based on charcoal pieces

Frequency dependences of EMR reflection coefficient in the range 0.7–17.0 GHz of construction based on charcoal pieces are presented in Figure 3.3. The measurements of this parameter were carried out in two modes: matched load mode (the studied sample was placed between the measuring antennas); short circuit mode (the studied sample was placed between the transmitting antenna and the metal plate). Further in the text will be called mode 1 and short circuit mode – mode 2.



a

b

Figure 3.3 – Frequency dependences of EMR reflection coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of the construction based on charcoal pieces: 1 – frequency dependences were obtained based on the measurement results in the mode 1; 2 – frequency dependences were obtained on the basis of the measurement results in the mode 2

It was found that EMR reflection coefficient value in the frequency range 0.7–17.0 GHz of the considered construction varies from –0.1 to –12.0 dB. The frequency dependence of EMR reflection coefficient of the construction, obtained on the basis of measurements in the mode 1, is a set of resonance curves that are asymmetric with respect to the center frequency. EMR reflection coefficient values of the considered design, obtained on the basis of measurement results in the mode 2, at resonant frequencies are lower on 2.0–5.0 dB than the similar values obtained in the mode 2. This allows to judge the absorbing properties of the considered construction.

To conduct studies of EMR reflection and transmission characteristics in the frequency range 0.7–17.0 GHz of powdered charcoal, samples were made on its basis in accordance with the methodology, which includes the following steps:

– charcoal grinding;

– preparation of a sheet of cellular polycarbonate with a thickness of 0.8 cm, a size of 0.3×0.4 $m^2$ and sealing one of the open ends of this sheet using adhesive tape;

– filling with powdered charcoal of each of the polycarbonate honeycombs;

– sealing another open end of the tank using adhesive tape.

The appearance of the sample made in accordance with the presented methodology is shown in Figure 3.4.

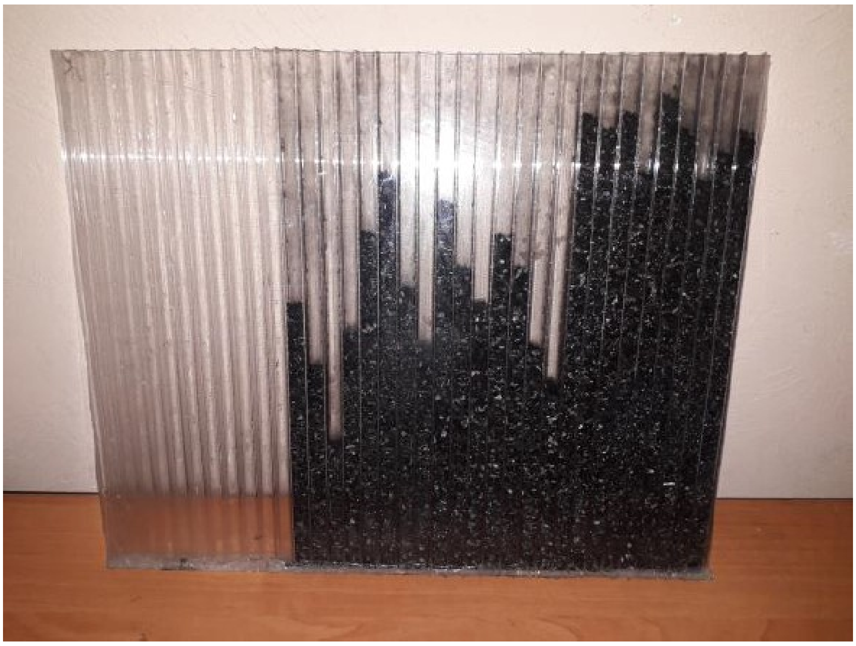
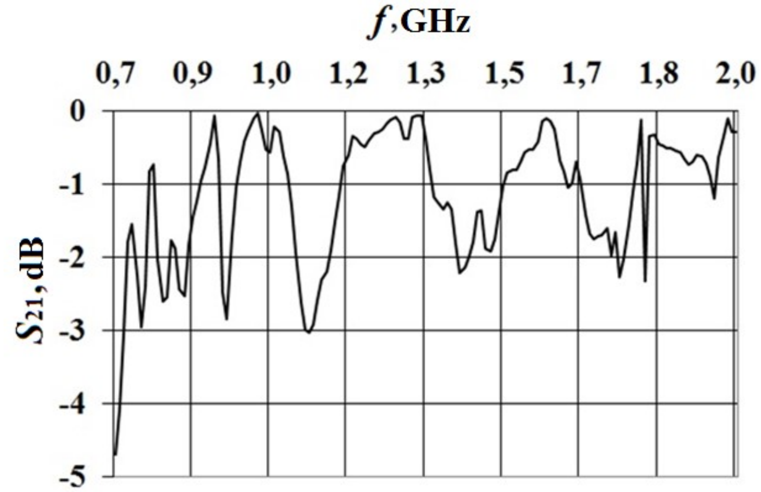
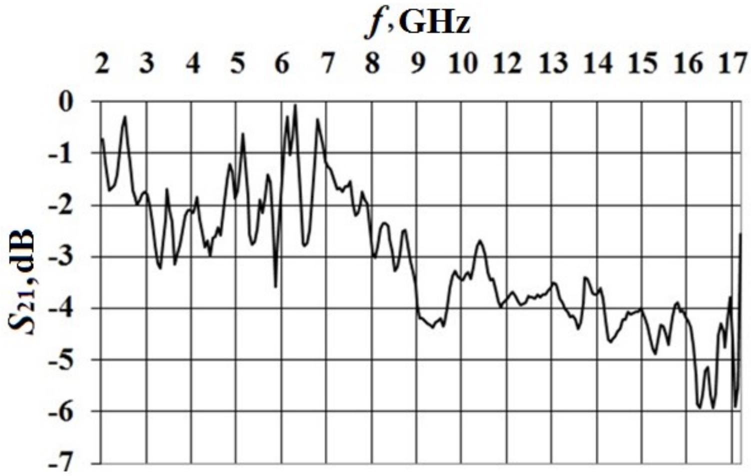


Figure 3.4 – The appearance of the sample in the form of the polycarbonate sheet filled with charcoal

Figure 3.5 shows the frequency dependence of EMR transmission coefficient in the range 0.7–17.0 GHz, of a charcoal-based sample obtained in accordance with the presented methodology.



a

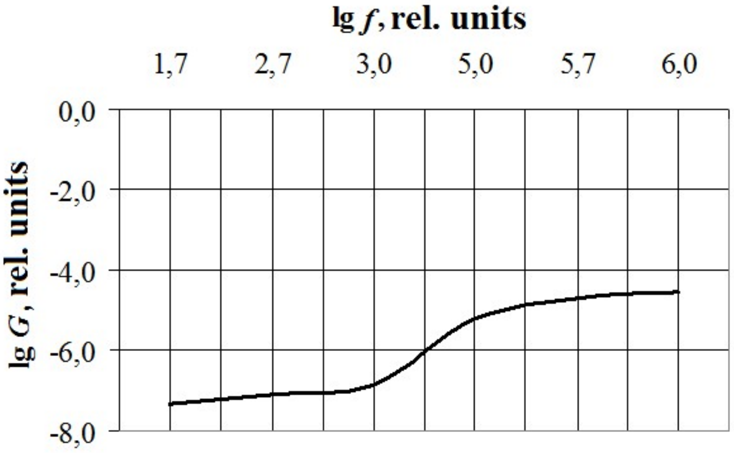


b

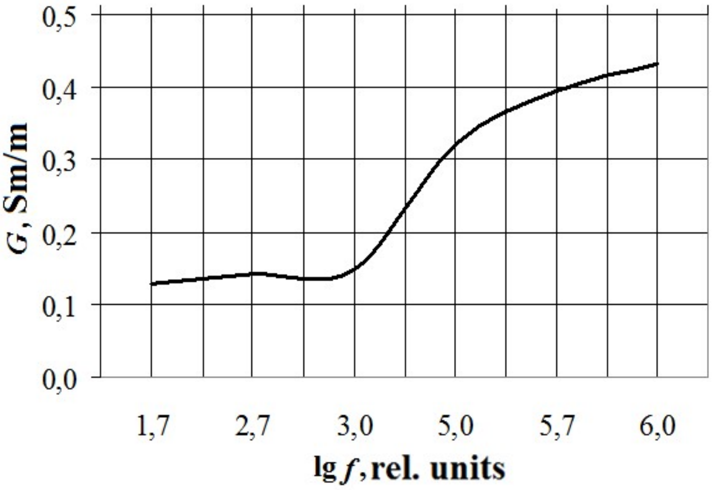
Figure 3.5 – Frequency dependences of EMR transmission coefficient in the range of 0.7–2.0 GHz (a), 2.0–17.0 GHz (b) of the sample in the form of the polycarbonate sheet filled with charcoal

It was found that the EMR transmission coefficient of the considered sample varies from –0.1 to –4.0 dB, which is explained by the low density of its filling with powdered charcoal.

It was determined that with an increase of EMR frequency, the transmission coefficient value of the shield based on powdered coal-containing materials decreases, due to an increase in their specific conductivity (*G*) (Figure 3.6).



a



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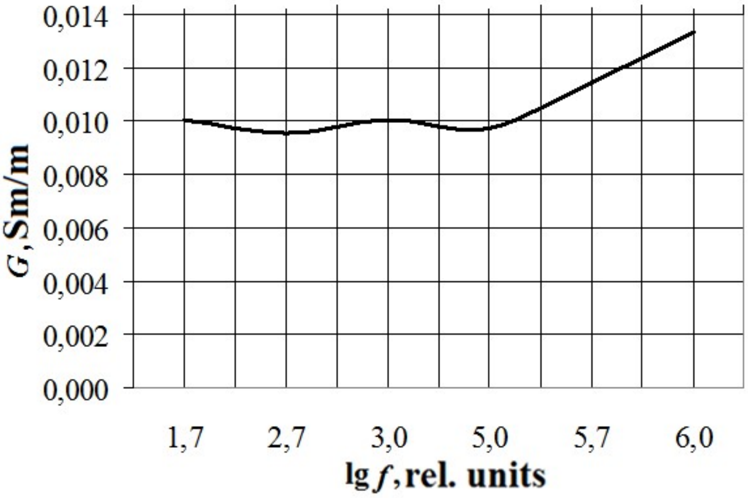
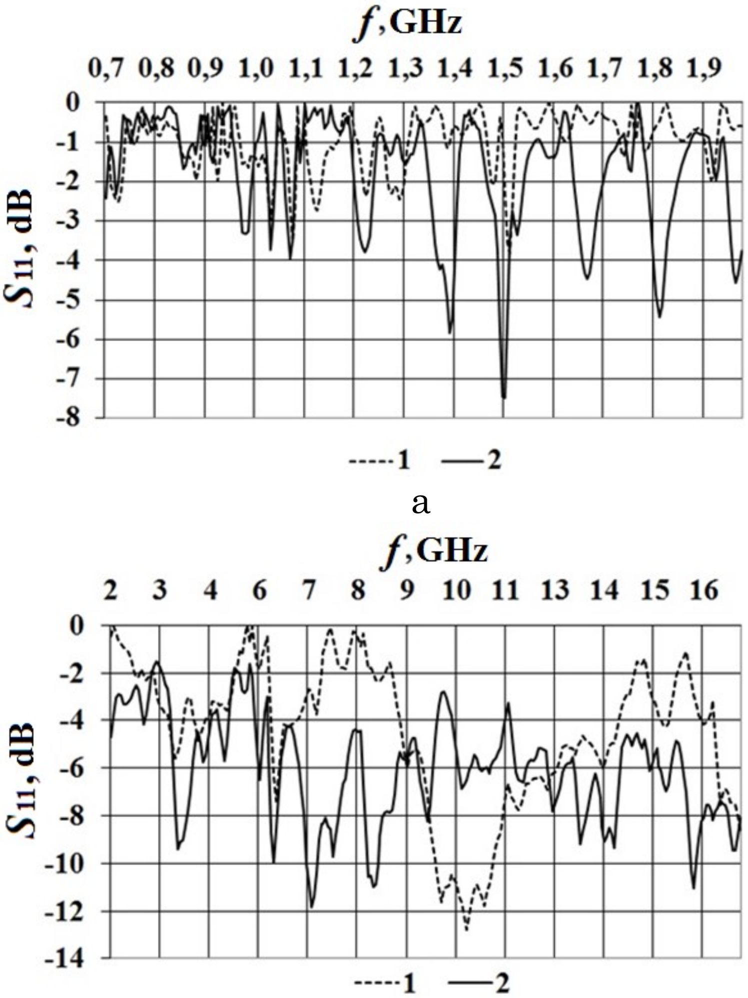


c

Figure 3.6 – Frequency dependences of the specific conductivity of powdered activated coal (a), charcoal (b) and coconut coal (c)

Figure 3.7 shows the frequency dependence of EMR reflection coefficient in the range 0.7–17.0 GHz of the sample in the form of the polycarbonate sheet filled with charcoal.



a

b

Figure 3.7 – Frequency dependences of EMR reflection coefficient in the range of 0.7–2.0 GHz (a), 2.0–17.0 GHz (b) of the sample in the form of the polycarbonate sheet filled with charcoal: 1 – frequency dependences were obtained based on the measurement results in the mode 1; 2 – frequency dependences were obtained on the basis of the measurement results in the mode 2

It was determined that EMR reflection coefficient values in the frequency range 0.7–2 GHz vary from –1.0 to –4.0 dB (when measured in the mode 1) and from –1.0 to –8.0 dB (when measured in the mode 2). In the frequency range 2.0–17.0 GHz, the considered parameter value varies from –2.0 to –10.0 dB. On the dependence of the EMR reflection coefficient from frequency in the indicated range, obtained on the basis of the measurement results in the mode 2, one resonance curve can be arbitrarily selected, the central frequency of which is 10 GHz. This curve is asymmetrical with respect to the center frequency.

## 3.2 Electromagnetic Radiation Reflection and Transmission Characteristics of Moisture-Containing Powdered Coals

To study EMR reflection and transmission characteristics in the frequency range 0.7–17.0 GHz of moisture-containing powdered coals samples based on it were made in accordance with the methodology, which includes the following steps:

– preparation of squared canvases from foamed polyurethane foam with the size 30 × 40 $cm^2$ (Figure 3.8, a);

– preparation of squared canvases from a mesh of cellular form made of plastic (polyethylene) with the size 30×40 $cm^2$ (Figure 3.8, b);

– location on top of the canvas based on foamed polyurethane foam canvas based on a polyethylene mesh (Figure 3.8, c);

– obtaining a powdered coal-containing material: grinding pieces of charcoal to a powder with a particle size of 0.7 mm or pieces of wood or coconut shell to a powder with a particle size of up to 0.2 mm;

– mixing the obtained powdered material with an aqueous solution of $CaCl_2$ (concentration is 30 wt.%) (Figure 3.8, d);

– applying the resulting pasty mixture with a layer of 2 mm thickness on the surface of the canvases based on foamed polyurethane foam and polyethylene mesh (Figure 3.8, e);

– the location of the canvases based on a polyethylene mesh on the top of the applied pasty mixture;

– location of the canvas based on foamed polyurethane foam on the top of the canvas based on a polyethylene mesh;

– sealing the resulting construction by placing it between rectangular canvases based on polyester film with 10 microns thickness and then connecting them along the perimeter of these canvases using the sealing method (Figure 3.8, f).

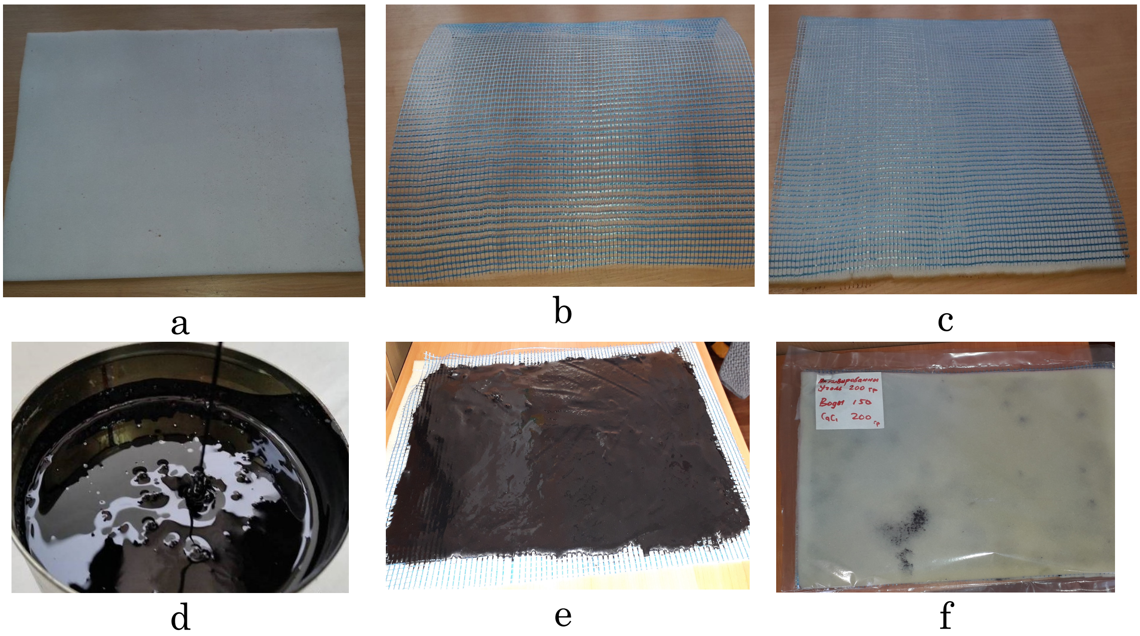


Figure 3.8 – Illustrations of the main steps of the manufacture of the electromagnetic shields samples based on moisture-containing powdered coals

The main advantage of the samples made in accordance with the specified methodology is the reduction of the possibility of changing the shape of the paste-like mass based on powdered coal during its mechanical compression due to the mesh.

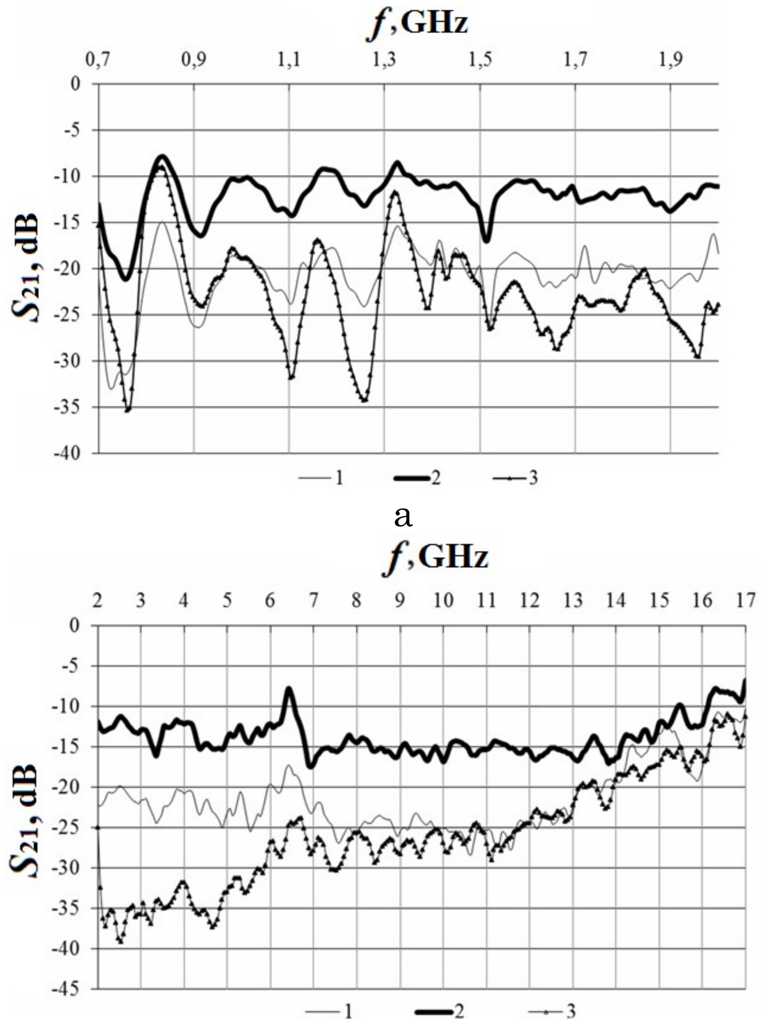
Figures 3.9–3.11 show the frequency dependences of EMR transmission and reflection coefficients in the range of 0.7–17.0 GHz for electromagnetic shields samples based on moisture-containing powdered coals.

It was established that EMR transmission coefficient values in the frequency range 0.7–17.0 GHz of electromagnetic shields based on moisture-containing powdered coals vary in the following limits:

1) from –10 to –15 dB – for shields based on moisture-containing charcoal;

2) from –20 to –25 dB – for shields based on water-containing activated coal;

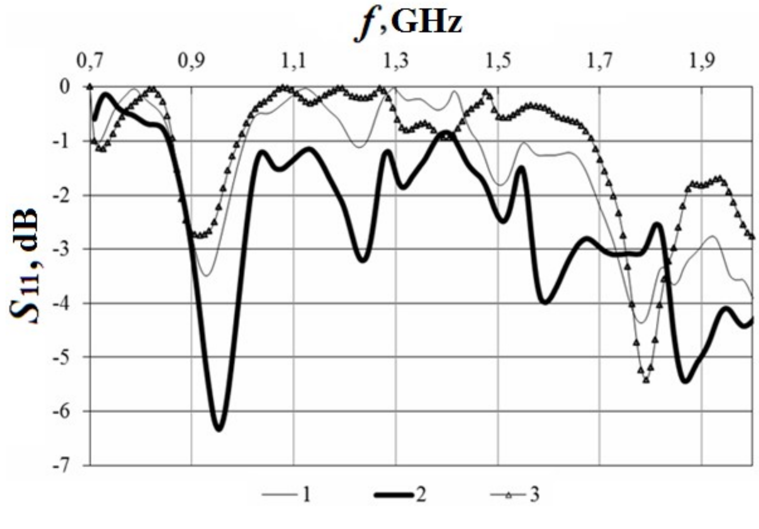
3) from –25 to –35 dB – for shields based on moisture-containing coconut coal.



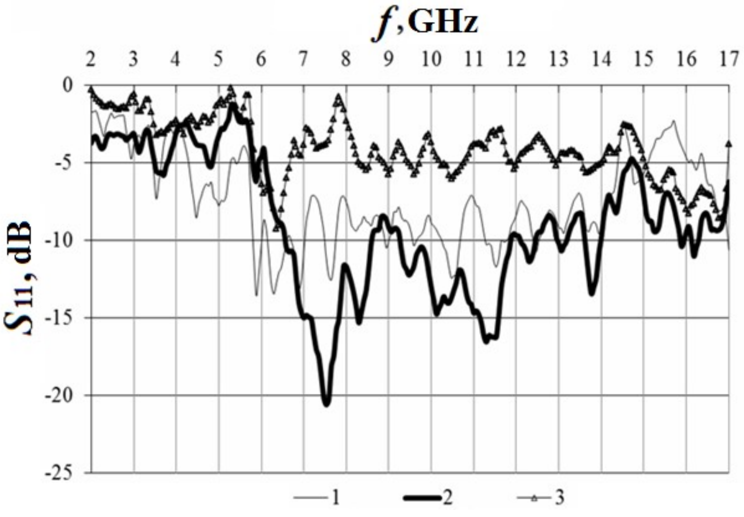
a

b

Figure 3.9 – Frequency dependences of EMR transmission coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of electromagnetic shields samples based on moisture-containing powdered coal:
1 – the sample based on activated coal;
2 – the sample based on charcoal;
3 – the sample based on coconut coal

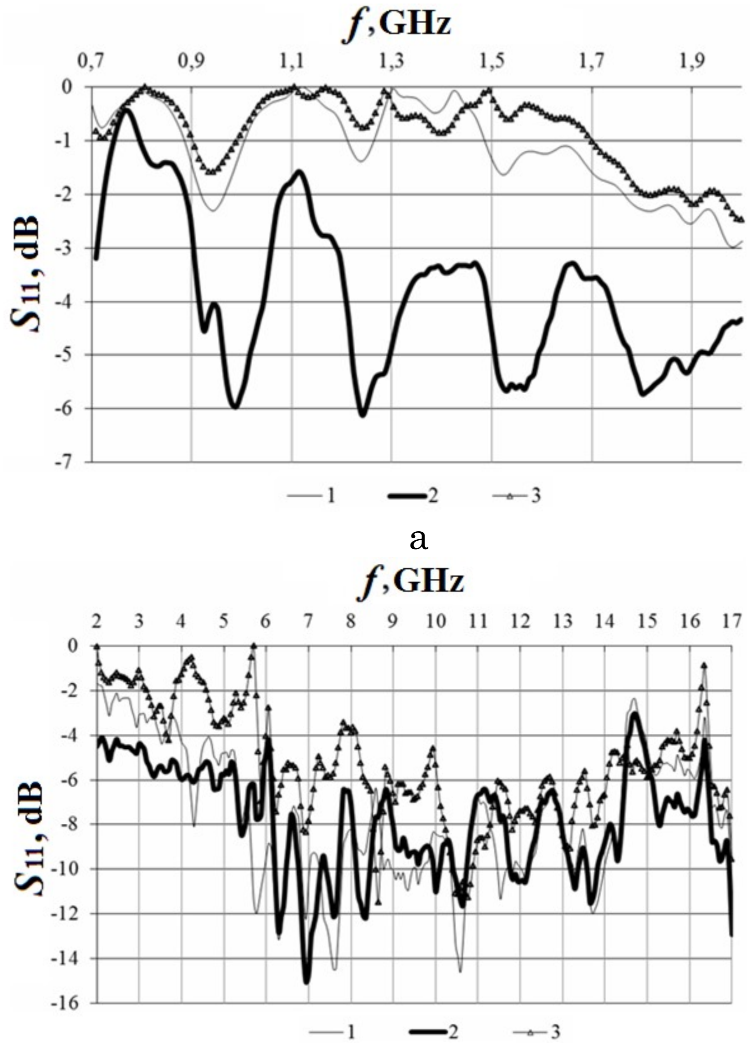


a



b

Figure 3.10 – Frequency dependences of EMR reflection coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of electromagnetic shields samples based on moisture-containing powdered coal, obtained on the base of measurement results in the mode 1:
1 – the sample based on activated coal;
2 – the sample based on charcoal;
3 – the sample based on coconut coal



a

b

Figure 3.11 – Frequency dependences of EMR reflection coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of electromagnetic shields samples based on moisture-containing powdered coal, obtained on the base of measurement results in the mode 2: 1 – the sample based on activated coal; 2 – the sample based on charcoal; 3 – the sample based on coconut coal

Shields based on moisture-containing coconut coal are characterized by lower EMR transmission coefficients compared to other studied shields because coconut coal particles are more hygroscopic compared to charcoal and activated coal particles because they contain more pores. These features determine that moisture-containing coconut coal is characterized by higher values of specific conductivity (G) in comparison with moisture-containing activated and charcoal (Figure 3.12).

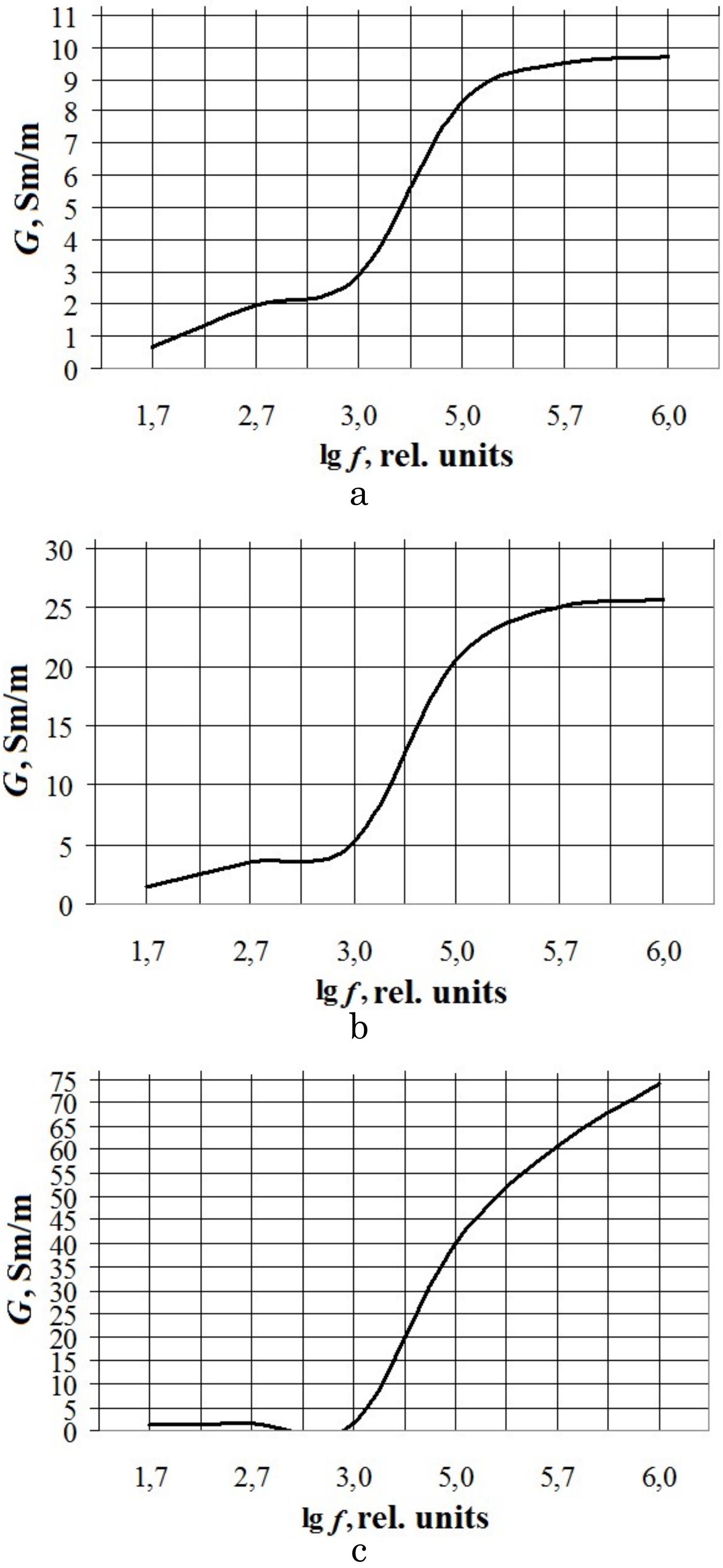


Figure 3.12 – Frequency dependences of the specific conductivity of powdered moisture-containing activated coal (a), charcoal (b) and coconut coal (c)

Electromagnetic shields based on moisture-containing charcoal differ in the lowest values of EMR reflection coefficient. These values range from –1.0 to –20.0 dB (for measurements in the mode 1) and from –1 to –14 dB (for measurements in the mode 2). Shields based on moisture-containing activated and coconut coals in the frequency range 0.7–2.0 GHz are characterized by EMR reflection coefficient values varying from –0.5 to –6.0 dB. In the frequency range of 2.0–17.0 GHz, the considered parameter values for such shields respectively vary from –2.0 to –15.0 dB and from –2.0 to –8.0 dB (for measurements in the mode 1). When measuring in the mode 2, EMR reflection coefficient values in the frequency range of 2.0–17.0 GHz of shields based on moisture-containing activated and coconut coals vary within –2.0 to –14.0 dB and –1.0 to –10.0 dB, respectively.

The lower values of the EMR reflection coefficient of shields based on moisture-containing charcoal are due to the fact that this material, in comparison with moisture-containing activated and coconut coals, is characterized by lower values of wave resistance.

## 3.3 Electromagnetic Radiation Reflection and Transmission Characteristics of Metal-Carbon Composites Based on Powdered Activated Coal

Currently, the use of metal-carbon composites, which are synthesized by incorporating metal clusters (fillers) into the pores of fractions of carbon powdered materials (matrices), is promising for the manufacture of electromagnetic shields. This is due to the electrically conductive properties of the latter, which cause high energy losses of the EMR interacting with them: as a rule, shields based on carbon powdered materials are characterized by EMR transmission coefficients of less than –40 dB in the radio frequency range [98]. In addition, based on metal-carbon composites, electromagnetic shields with the required radio shielding properties (attenuation and EMR reflection coefficient, resonant frequencies) can be obtained. This is achieved by controlling the composition of metal clusters in the pores of carbon powdered materials fractions, which is ensured, as a rule, by choosing methods or modes of modifying their composition. As a rule, the initial stage of any process associated with modifying the carbon powdered materials composition, in particular, with the synthesis of metal-carbon composites, involves activating and sensitizing the surface of these materials fractions, which is necessary to increase their porosity.

In order to optimize the synthesis of metal-carbon composites, in the present work, it was proposed to use powdered activated coal as a matrix for them. Its porosity is ≈ 90 %, which provides conditions for eliminating the need for the activation and sensitization of its fractions surface in the process of its composition modifying, which means reducing the time and material costs of such a process.

### 3.3.1 The Method of Obtaining and Electromagnetic Radiation Reflection and Transmission Characteristics of Nickel-Containing Activated Coal

The regularities of EMR interaction with metal-carbon composites based on nickel-containing activated coal were studied depending on the composition of the water solutions used for their synthesis. The choice of nickel as a metal included in the form of clusters in the powdered activated coal pores is due to its ferromagnetic properties. In this regard, by deposition of nickel clusters into the powdered activated coal pores, it is possible to reduce its wave resistance, and hence to change the radio shielding properties. The choice of this deposition method is due to the relatively low temperature required for its implementation. In addition, nickel clusters deposited from the water solutions are characterized by resistance to environmental influences. For the chemical deposition of nickel clusters on the powdered activated coal fractions surface, two types of the water solutions were used. The solution of the first type included nickel sulfate and ammonium chloride, the solution of the second type included nickel chloride and citric acid. The pH values of the solutions were 6.5–8 and 8.5–9, respectively. The reducing agent was sodium hypophosphite. The temperature of the solutions required for the precipitation of nickel clusters is 85 °C.

To study the laws of EMR interaction with synthesized composites, samples were made that consisted of cuvettes filled with powdered activated carbon. These cuvettes were made of a solid polymer, the thickness of which was 0.2±0.05 mm. The thickness of the samples is 3±0.2 mm. Three types of samples were investigated. Sample 1 was made of powdered activated coal, the composition of which was unmodified, samples 2 and 3 were made of a composite based on powdered activated coal, the composition of which was modified using solutions of the first and second types, respectively. It was established that the modification of the powdered activated coal composition by the method of chemical deposition of nickel clusters affects the values of its EMR reflection coefficient in the frequency range 8.0–12.0 GHz. EMR transmission of powdered activated coal is more than 40.0 dB in the studied frequency range. The frequency dependences of EMR reflection coefficient in the range of 8.0–12.0 GHz of the samples obtained as a result of measurements in the mode 1 are presented in Figure 3.13.

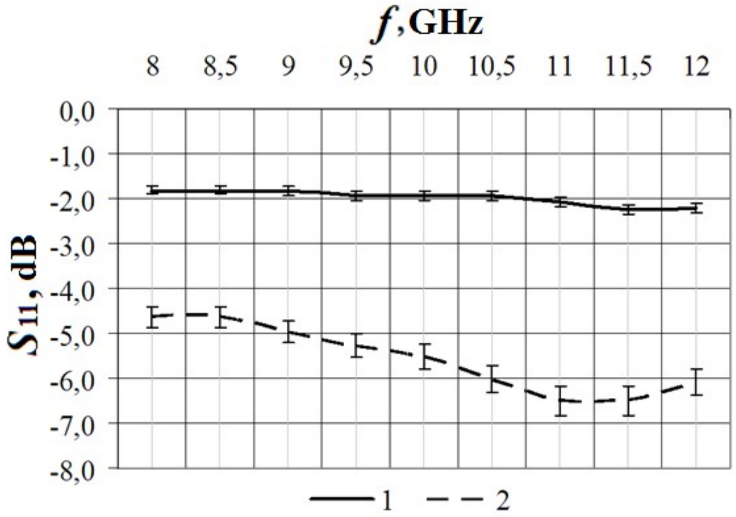


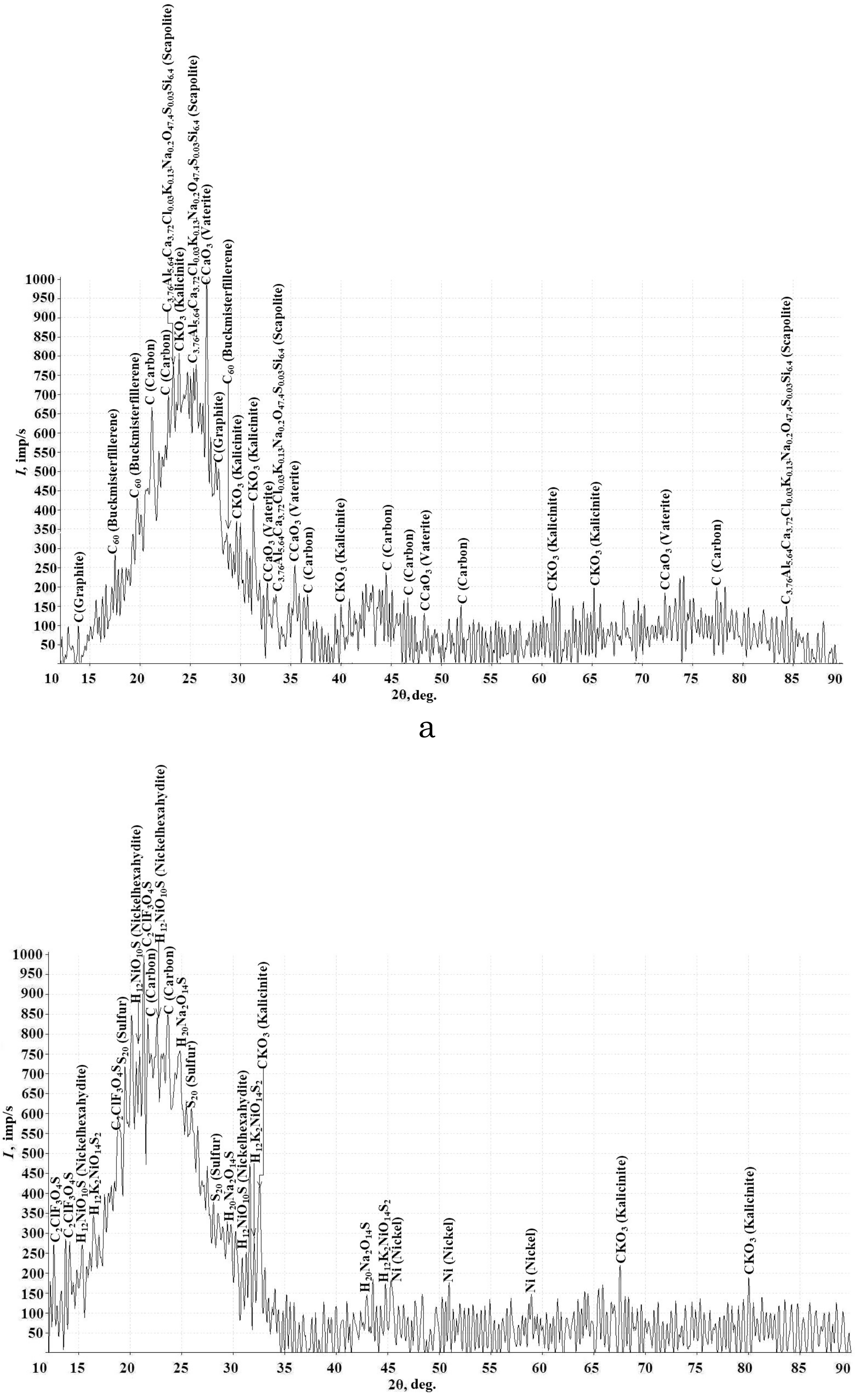
Рисунок 3.13 – Frequency dependences of EMR reflection coefficient in the range of 8.0–12.0 GHz of the studied samples obtained as a result of measurements in the mode 1:
1 – sample 1; 2 – samples 2 and 3

According to the Figure 3.13, powdered activated coal is characterized by EMR reflection coefficient of –2.0±0.2 dB. Chemical deposition of nickel clusters from the water solutions led to a decrease in its reflection coefficient by 3.0–4.0 dB ± 0.2 dB. This is due to the fact that activated coal, the composition of which is modified by deposition of nickel clusters from the water solutions, contains less carbon elements compared to activated coal, the composition of which is unmodified (Figure 3.14). As a result, the impedance of the first is lower than the second.

It follows from the Figure 3.14 that the powdered activated coal, the composition of which is unmodified, contains 100 % carbon elements. Chemical deposition of nickel clusters from the water solution of the first type on the surface of powdered activated coal fractions led to the formation of sulfur and sulfur-containing elements, such as: $S_{20}$, $H_{20}Na_2O_{14}S$, $H_{12}K_2NiO_{14}S_2$, $C_2ClF_3O_4S$ (the total percentage of these elements was 84.3 wt.%), nickel-hexahydite (14.1 wt.%). The percentage of the nickel was 0.1 mass. %. Powdered activated coal, the composition of which is modified using the water solution of the second type, contained 32.2 mass. % of the carbon, 20 mass. % of the bakmisterfillerena and 0.4 mass. % of the nickel.

The frequency dependences of EMR reflection coefficient in the range of 8–12 GHz of the fabricated samples obtained as a result of measurement in mode 2 are shown in Figure 3.15.

According to the analysis of the characteristics shown in Figure 3.15, it was found that EMR reflection coefficient values of sample 1 don’t depend on the mode of their measurements. This is due to the fact that most of the electromagnetic waves interacting with this sample are reflected by its surface. This feature is due to the large difference between the wave resistances of air and powdered activated coal, the composition of which is unmodified [99].



a

b

Figure 3.14 – Diffraction patterns of powdered activated coal with unmodified composition (a) and with composition modified by chemical deposition of nickel clusters from the water solutions (b)

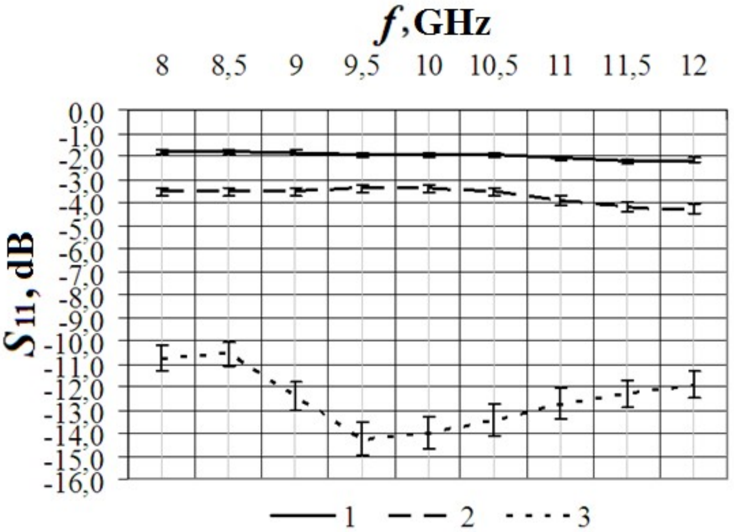


Figure 3.15 – Frequency dependences of EMR reflection coefficient in the range of 8.0–12.0 GHz of the studied samples obtained as a result of measurements in the mode 2:
1 – sample 1; 2 – sample 2; 3 – sample 3

According to the analysis of the characteristics shown in Figures 3.13 and 3.15 EMR reflection coefficient values in the frequency range 8.0–12.0 GHz for sample 2, measured in the mode 2, are higher on 1.0±0.1–1.5±0.1 dB than the corresponding values measured in the mode 2. For sample 3, on the contrary, EMR reflection coefficient values measured in the mode 2 are lower on 6.0±0.3–9.0±0.3 dB than the values measured in the mode 1. This is due to the percentage of electrically conductive components in the powdered activated coal, the composition of which is modified using the solution of the first type, which is more than 2.5 times higher than the percentage of electrically conductive components in the powdered activated coal, the composition of which is modified using the solution of the second type. These components cause the attenuation of the energy of electromagnetic waves reflected from a metal plate. Such attenuation is a consequence of the phase difference between the waves reflected from the metal plate and the waves reflected from the surface of the sample.

The resonance frequency of sample 3 is 9.5±0.2 GHz.

The corresponding EMR reflection coefficient is –14.0±0.5 dB. The occurrence of resonance is due to the fact that at the indicated frequency the largest phase difference of electromagnetic waves reflected by the surfaces of the cell filled with the synthesized nanocomposite and the metal plate [99].

Thus, to regulate EMR reflection coefficient values and the resonance frequency of electromagnetic shields based on powdered activated coal by chemical deposition of nickel clusters on the surface of its particles, the water solution based on nickel chloride (crystalline hydrate) and sodium citric acid should be used. The results can be used to solve the problem of reducing the energy of standing waves in shielded rooms [100].

### 3.3.2 The Method of Obtaining and Electromagnetic Radiation Reflection and Transmission Characteristics of Copper-Containing Activated Coal

The characteristics of EMR transmission and reflection of metal-carbon composites based on powdered activated coal, the composition of which is modified by chemical deposition of copper clusters on its surface from the water solutions, were studied. The main advantage of this method of metal-carbon composites synthesis is the relatively low temperature required for its implementation. In addition, copper clusters deposited from the water solution are characterized by low porosity and high resistance to environmental conditions. Copper is an electrically conductive material. The structure of the fine mesh formed by the fractions of powdered activated coal can change after the chemical deposition of copper clusters on their surface. As a result, the amplitude of the electromagnetic waves scattered on this grid can be changed.

The water solution used to precipitate the copper clusters included potassium sodium tartrate, copper sulfate (crystalline hydrate) and sodium hydroxide. Its pH value was 12.8. The 40 % formalin solution was used as a reducing agent. The temperature of the solutions was 60–65 °C.

The chemical precipitation process included the following steps.

1. Flushing powdered activated carbon using distilled water.
2. Mixing the components to obtain the required water solution.
3. Heating the water solution to a temperature necessary for the occurrence of cluster deposition reactions.
4. Immersion of powdered activated coal in a heated water solution and the reaction of the restoration of metal clusters.
5. Extraction of the modified powdered activated caoal from the water solution.
6. Stabilization reaction of the deposited metal clusters on the powdered activated coal fractions surface using a surfactant.
7. Rinsing of the modified powdered activated coal using distilled water and drying under standard conditions.

For a comparative study of EMR transmission and reflection characteristics metal-carbon composites synthesized in accordance with the above method, two types of samples were made: sample 1 was based on unmodified powdered activated coal, sample 2 was based on synthesized in accordance with the above method, metal-carbon composite in the form of activated coal, the composition of which is modified by chemical deposition of copper clusters. The approach used for the manufacture of these samples was similar to the approach used in the manufacturing process of the samples presented in the Subsection 3.3.1.

It has been established that the modification of powdered activated coal by chemical deposition of metal clusters affects to its EMR reflection coefficient values in the frequency range 8.0–12.0 GHz. EMR transmission coefficient in the indicated frequency range of unmodified and modified powdered activated coal is more than 40 dB. The frequency dependences of EMR reflection coefficient in the range of 8.0–12.0 GHz of the fabricated samples obtained as a result of measurements in the mode 1 are presented in Figure 3.16.

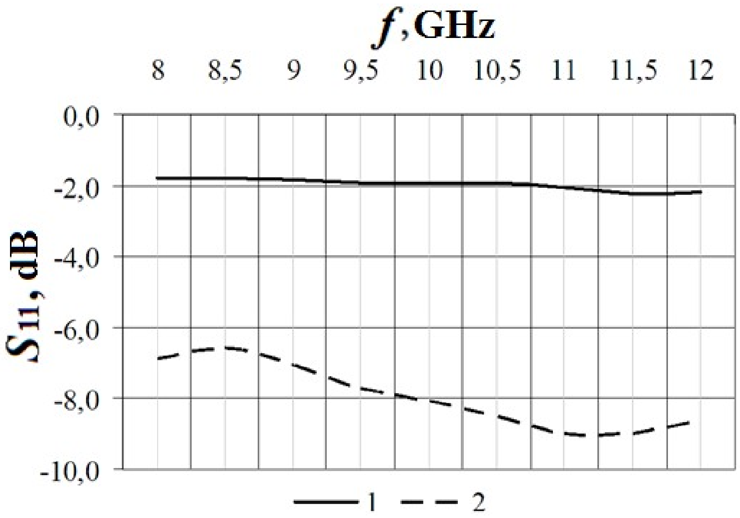


Figure 3.16 – Frequency dependences of EMR reflection coefficient in the range of 8.0–12.0 GHz of the studied samples obtained as a result of measurements in mode 1:
1 – sample 1; 2 – sample 2

According to Figure 3.16, the chemical deposition of copper clusters from the water solutions led to a 5.0–7.0 dB decrease in EMR reflection coefficient of powdered activated coal. This is due to the fact that modified activated coal contains less carbon elements compared to unmodified ones, as a result of which its wave impedance is lower.

It has been found that unmodified powdered activated coal contains 100 % of the carbon elements. After chemical deposition of copper on the surface of powdered activated coal particles, clusters based on it (1.9 wt.%) were formed (Figure 3.16). It was also 26.3 wt. % of calicinitis, 51.4 wt. % of the sulfur and the sulfur-containing element ($H_{20}Na_2O_{14}S$), 10.8 wt. % of the copper-containing compound ($CuH_{12}O_{14}Rb_2Se_2$), 9.2 wt. % of graphite in the composition of powdered activated coal modified by the chemical deposition of copper clusters (Figure 3.17).

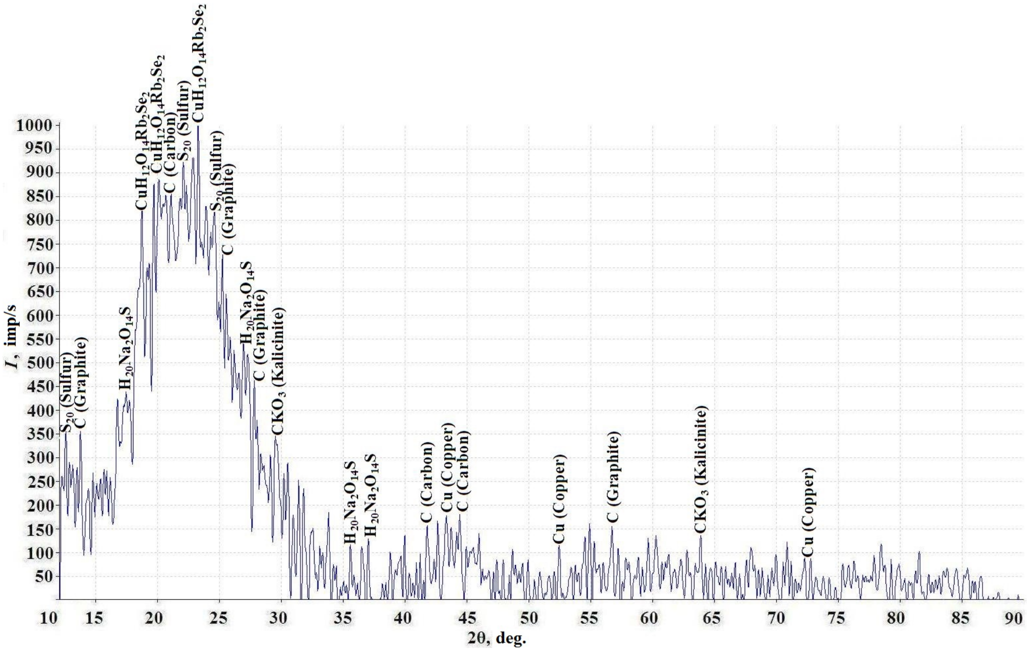


Figure 3.17 – Diffraction pattern of powdered activated carbon with composition modified by chemical deposition of copper clusters from the water solution

The frequency dependences of EMR reflection coefficient in the range of 8.0–12.0 GHz of the samples obtained as a result of measurements in the mode 2 are presented in Figure 3.18.

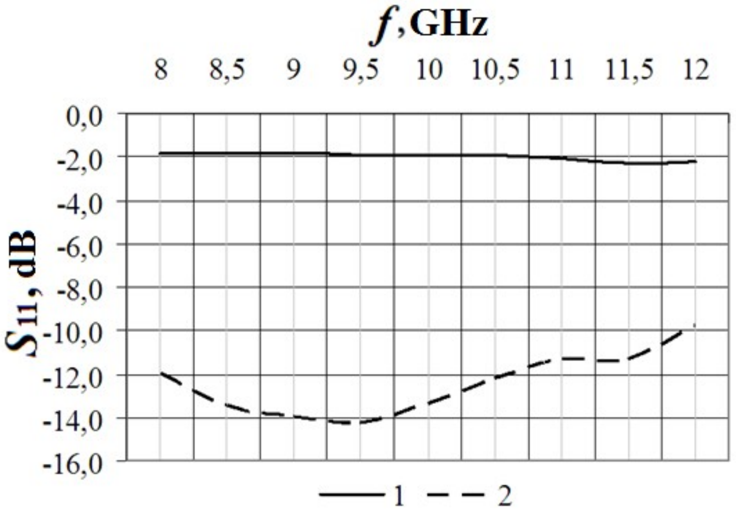


Figure 3.18 – Frequency dependences of EMR reflection coefficient in the range of 8.0–12.0 GHz of the studied samples obtained as a result of measurements in mode 2:
1 – sample 1; 2 – sample 2

According to the analysis of the characteristics presented in Figure 3.18, it was found that EMR reflection coefficient values in the frequency range of 8.0–12.0 GHz of metal-carbon composites containing copper clusters measured in the mode 2 are lower on 2.0–6.0 dB than the similar parameter values measured in the mode 1.

The minimum value of EMR reflection coefficient of the considered composite is –14.0±0.5 dB and corresponds to a frequency of 9.5±0.2 GHz. This frequency is resonant.

Thus, EMR reflection coefficient values of metal-carbon composites based on powdered activated coal containing nickel or copper clusters are lower on 2.0–7.0 dB than the a similar parameter values of activated coal with an unmodified composition [101].

# 4 THE DEVELOPMENT METHODS AND PROPERTIES OF ELECTROMAGNETIC SHIELDS BASED ON POWDERED COAL-CONTAINING MATERIALS

## 4.1 Electromagnetic Shields with Composite Coal-Containing Coatings

The effect of the composition of composite coal-containing coatings of electromagnetic shields on the values of EMR transmission and reflection of the latter is investigated. Non-woven cellulosic materials were used as the basis for the manufacture of electromagnetic shields with composite coal-containing coatings, due to their following advantages: good adhesive properties, sorption ability, breathability, hygroscopicity. These advantages are associated with the capillary-porous colloidal nature of the cellulosic materials structure. The presented properties of cellulosic materials are most determined by the fractional composition of their fibers, in the intervals of which air and water inclusions are contained [102, 103].

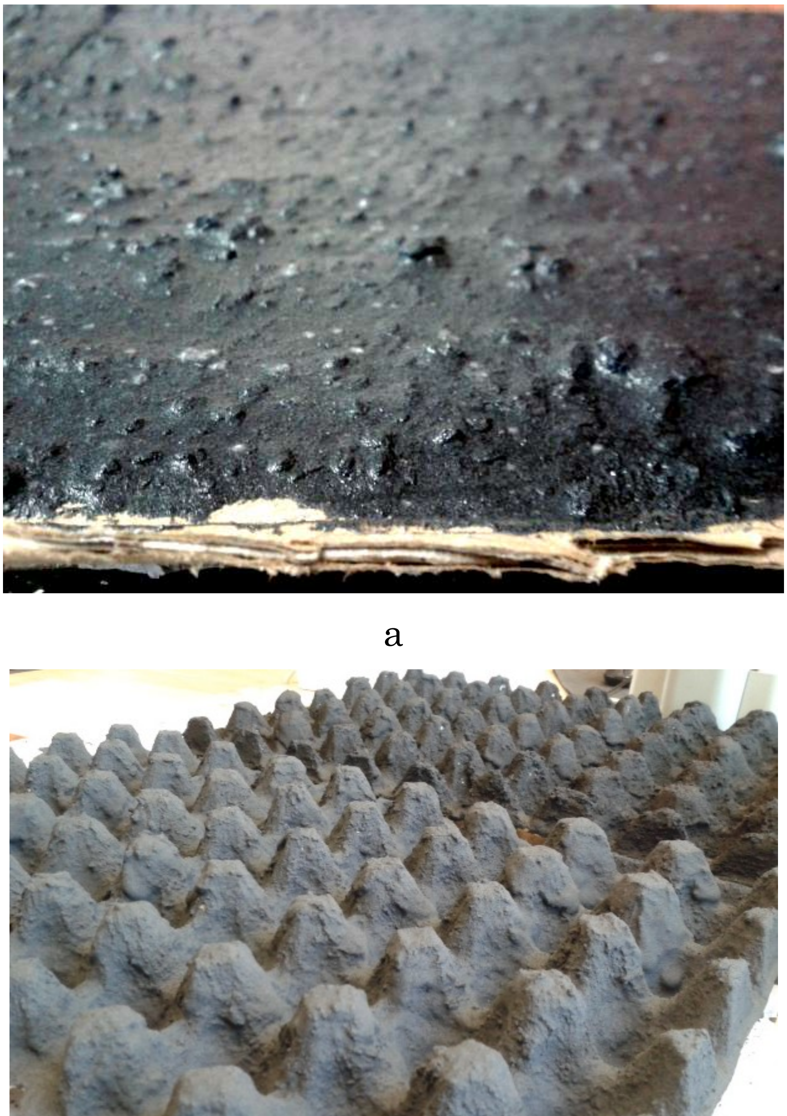
The electromagnetic shields samples with composite coal-containing coatings made for research can be conditionally divided into two groups:

– group 1: shields with a flat surface (Figure 4.1, a);

– group 2: shields, the surface of which is truncated pyramids set with a height of 4.5 cm (Figure 4.1, b).

The basis of electromagnetic shields samples of group 1 were flat sheets of dense cellulosic material, the shields of group 2 were hollow solid-state forms made of pressed cellulosic material, which are a collection of hollow truncated pyramids.

To ensure the least reflection from the external surface of the sample facing the EMR source, it is necessary to realize a smooth transition of wave characteristics from air to the working material of the shield. For these purposes, the structure or shape is added to the sample, increasing its active surface. When it falls onto such a surface, an electromagnetic wave is reflected many times and loses much more energy than when it falls on a flat surface. Thus, as a result of using forms representing a combination of hollow truncated pyramids as the basis for the manufacture of electromagnetic shields with composite coal-containing coatings, it is possible to increase the active surface of these shields, and therefore, reduce the values of their EMR reflection coefficient.


a

b

Figure 4.1 – Appearance of electromagnetic shields samples with composite coal-containing coatings:
a – sample with a flat surface; b – sample with a surface in the form of pyramids set

The manufacturing process of composite carbon-containing coatings for electromagnetic screens included the following steps.

*Step* 1. Grinding of charcoal pieces in an electric small-sized mill (the particle size obtained by grinding this powder was 30–40 microns).

*Step* 2. Mixing powdered charcoal with powdered titanium dioxide ($TiO_2$) (in the manufacture of electromagnetic shields samples of a certain kind).

*Step* 3. Impregnation of powdered charcoal or a mixture of powdered charcoal and $TiO_2$ with the water solution of calcium chloride ($CaCl_2$) with a concentration of 45 mass. % (in the manufacture of electromagnetic shields samples of a certain type).

*Step* 4. Mixing the obtained powdered coal-containing material with a binder ("Agniterm" water dispersion composition (WDC), glycerin ($C_3H_8O_3$) or polyvinyl acetate (PVA) glue, depending on the type of the manufactured electromagnetic shield).

The choice of titanium dioxide as an additional component of the composite coal-containing coating is due to its good sorption ability. Titanium dioxide is white crystals, which, when mixed in water, are easily peptized with the formation of stable colloidal solutions [104–107].

The author of the paper [108] demonstrated the possibility of obtaining of shielding coatings based on powdered titanium dioxide, characterized by EMR transmission and reflection coefficients in the frequency range 8.0–12.0 GHz, varying from –10 to –18 dB and from –2 to –6 dB, respectively.

The use of the water solutions of alkaline earth metals for the manufacture of composite shielding coatings increases the efficiency of EMR absorption by the latter, due to the ability of water to interact with EMR. It was shown in the paper [109] that by controlling the content of the water solutions in electromagnetic shields, it is possible to vary their EMR reflection coefficient values in the radio frequency wavelength range from –4.0 to –7.0 dB (for shields with a flat surface) and from –9.0 to –21.0 dB (for shields, the surface of which is a set of geometric heterogeneities). Based on the reference data [110], calcium chloride, which is a non-toxic, highly soluble, hygroscopic alkaline earth metal salt, has the highest hydration energy. The formation of chemical bonds between the ions of a dissociated alkaline earth metal salt and water molecules leads to the formation of hard compounds that prevent the evaporation of water molecules from the surface and the composition of the powdery filler, thereby preserving the initial moisture content of the composite shielding coating.

The use of these binders for the manufacture of composite coal-containing coatings led to the plasticity of the latter. Coatings with this property are characterized by good applicability.

Composite coal-containing coatings made by the implementation of the presented steps were applied with a layer of 0.2 cm thickness on the basis of cellulosic material. The duration of the process of bulk polymerization of coatings ranged from 10 to 24 hours, depending on the type of binder used during their manufacture.

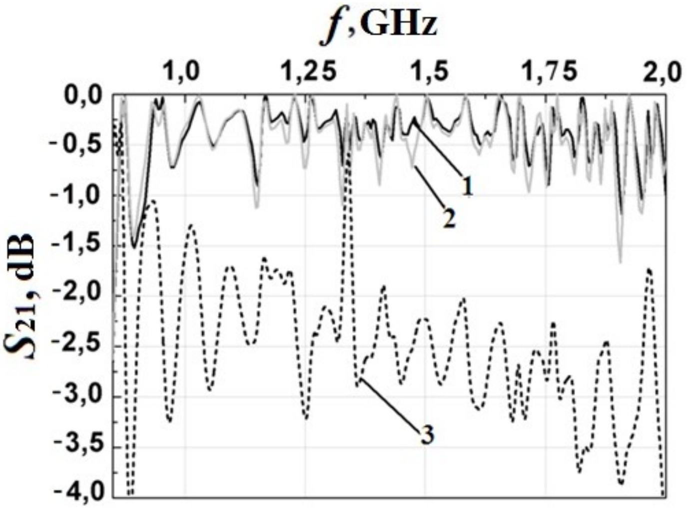
Table 4.1 presents the characteristics of electromagnetic shields samples made on the basis of these coatings.

Table 4.1 – Characteristics of manufactured electromagnetic shields samples based on composite coal-containing coatings

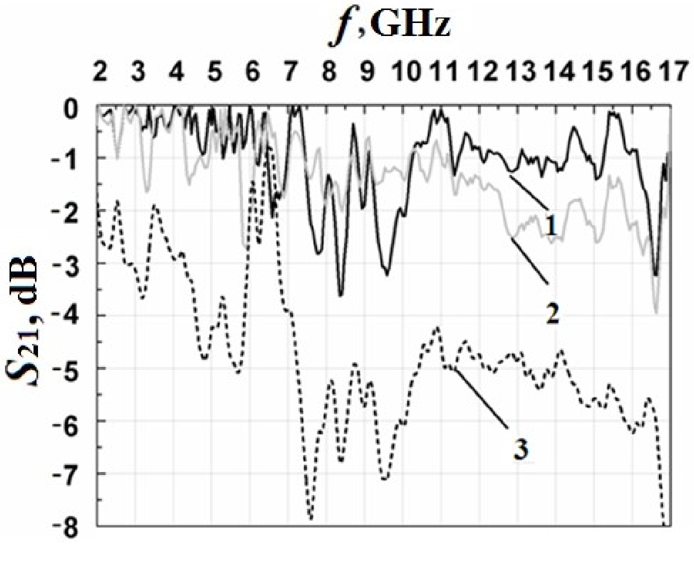
| Shield sample symbol | Name of the group to which the shield sample belongs | The presence of $TiO_2$ | The presence of $CaCl_2$ water solution | Used binder |
|---|---|---|---|---|
| No. 1 | Group 1 | No | No | “Agniterm” WDC |
| No. 2 | Group 1 | No | Yes | “Agniterm” WDC |
| No. 3 | Group 1 | Yes | Yes | $C_3H_8O_3$ |
| No. 4 | Group 2 | Yes | Yes | $C_3H_8O_3$ |
| No. 5 | Group 2 | Yes | Yes | PVA |

EMR transmission and reflection characteristics of manufactured electromagnetic shields samples were studied.

Figures 4.2–4.4 show the frequency dependences of EMR transmission and reflection coefficients in the range 0.7–17 GHz of electromagnetic shields samples of group 1.

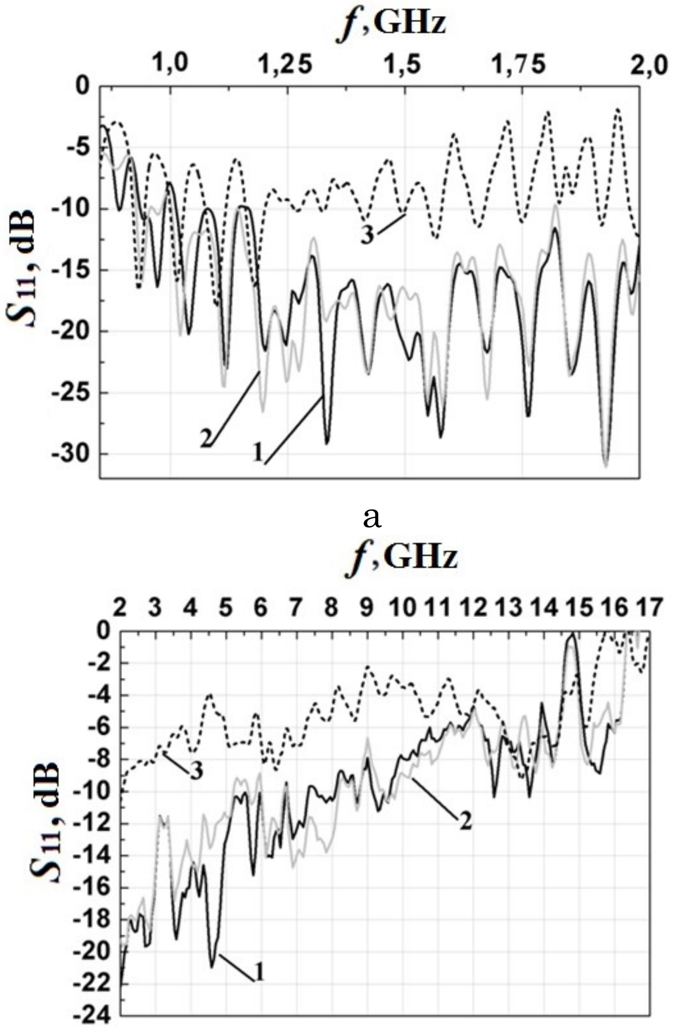


a



b

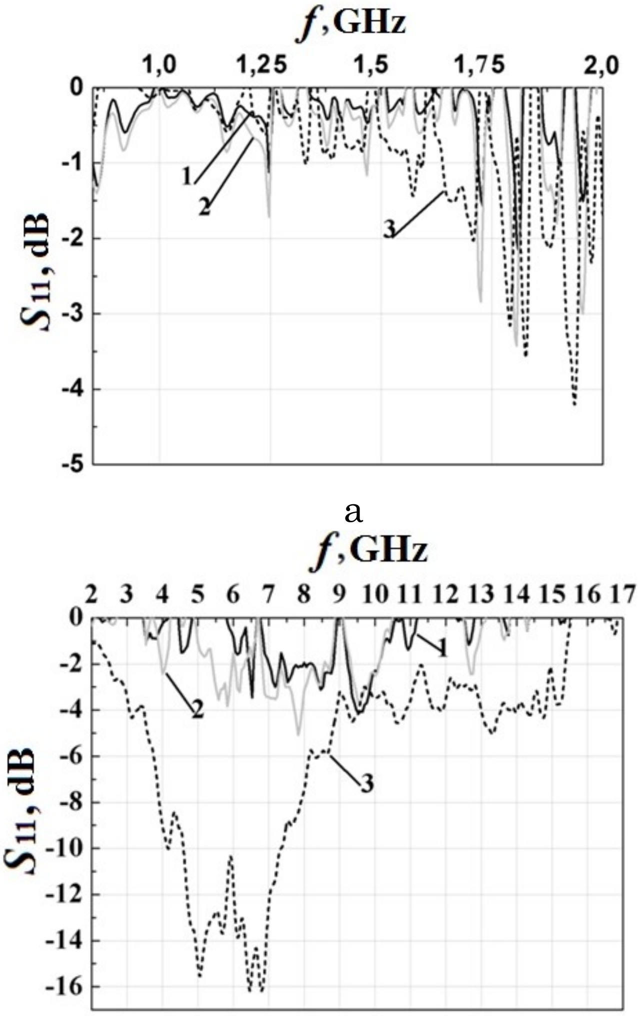
Figure 4.2 – Frequency dependences of EMR transmission coefficient in the range 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of electromagnetic shields samples of group 1:
1 – sample No. 1; 2 – sample No. 2; 3 – sample No. 3



a

b

Figure 4.3 – Frequency dependences of EMR reflection coefficient in the range 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of electromagnetic shields samples of group 1 obtained as a result of measurements in mode 1: 1 – sample No. 1; 2 – sample No. 2; 3 – sample No. 3



a

b

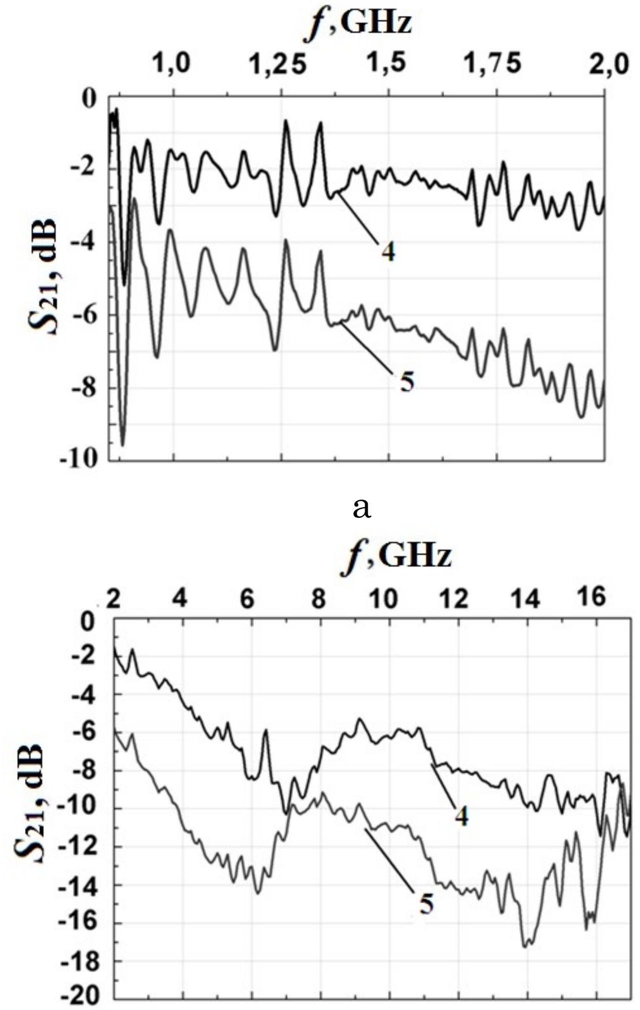
Figure 4.4 – Frequency dependences of EMR reflection coefficient in the range 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of electromagnetic shields samples of group 1 obtained as a result of measurements in mode 2: 1 – sample No. 1; 2 – sample No. 2; 3 – sample No. 3

It was found that electromagnetic shields of group 1 with coatings based on powdered charcoal are characterized by the EMR transmission coefficient values, which vary from –0.1 to 1.5 dB in the frequency range 0.7–2.0 GHz. When using a combined coating for the manufacture of an electromagnetic shield, containing, in addition to powdered charcoal, powdered titanium dioxide, it is possible to provide for such a shield EMR transmission coefficient values, varying from –1.0 to –4.0 dB. EMR reflection coefficient values in the frequency range

0.7–2.0 GHz for electromagnetic shields of group 1 with charcoal-based coatings, measured in the mode 1, vary within from –5.0 to –30.0 dB, and for shields of the same group with combined coatings – from –3.0 to –15.0 dB (the average value of the considered parameter for such shields is –10.0 dB). EMR reflection coefficient values of electromagnetic shields of group 1, measured in the mode 2, significantly exceed the values of the same parameter for these shields, measured in the mode 1, and, regardless of the composition of the composite carbon-containing coating, vary from –0.1 to –4.0 dB in the frequency range 0.7…2.0 GHz.

With an increase in the frequency within the range of 2.0–17.0 GHz, a decrease of 2.0–4.0 dB of EMR transmission coefficient values of the studied electromagnetic shields of group 1 is observed (see Figure 4.2). So, in the frequency range 2.0–17.0 GHz, EMR transmission coefficient values of electromagnetic shields with coatings based on powdered charcoal vary from –1.0 to –3.0 dB, and screens with combined coatings vary from –4.0 to –8.0 dB. In this case, EMR reflection coefficient in the frequency range 2.0–17.0 GHz for electromagnetic shields of group 1 with coatings based on powdered charcoal is from –0.1 to –20.0 dB, and for shields with combined coatings, from –2.0 to –10.0 dB. Lower values of EMR transmission coefficient and higher values of EMR reflection coefficient of electromagnetic shields with combined coatings obtained in the mode 1 are associated with a higher level of moisture content of the latter. EMR reflection coefficient of these shields, measured in the mode 2, is significantly lower than the values of the same parameter for shields with coatings based on powdered carbon-containing materials due to the large phase difference of electromagnetic waves reflected by the surfaces of the first of these shields and the surface of a short circuit (metal plate).

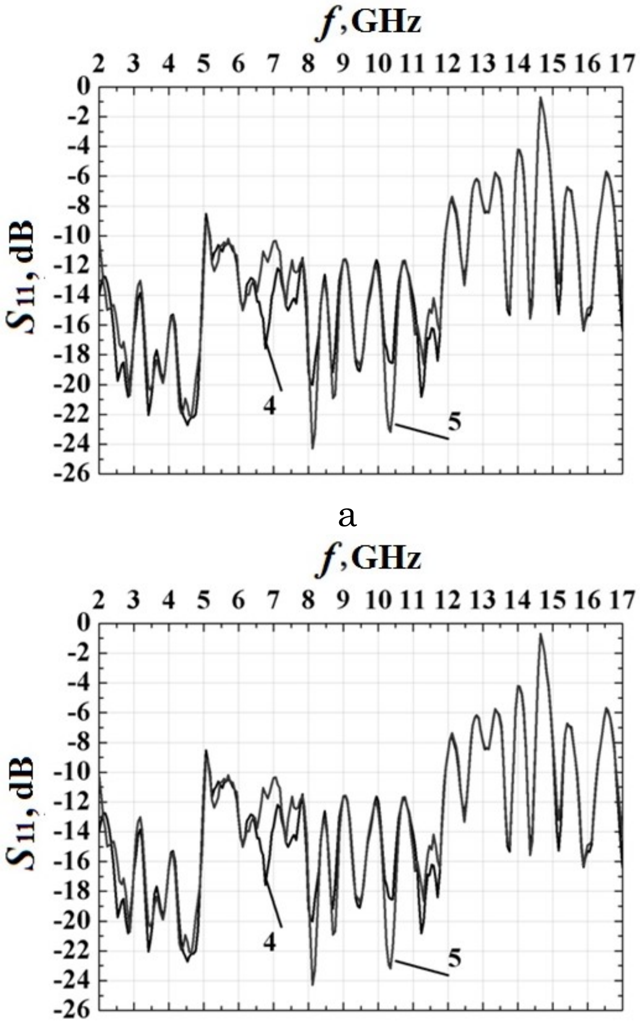
The frequency dependences of EMR transmission and reflection coefficients in the range of 0.7–17.0 GHz of the studied samples of electromagnetic shields of group 2 are presented in Figures 4.5–4.7.



a

b

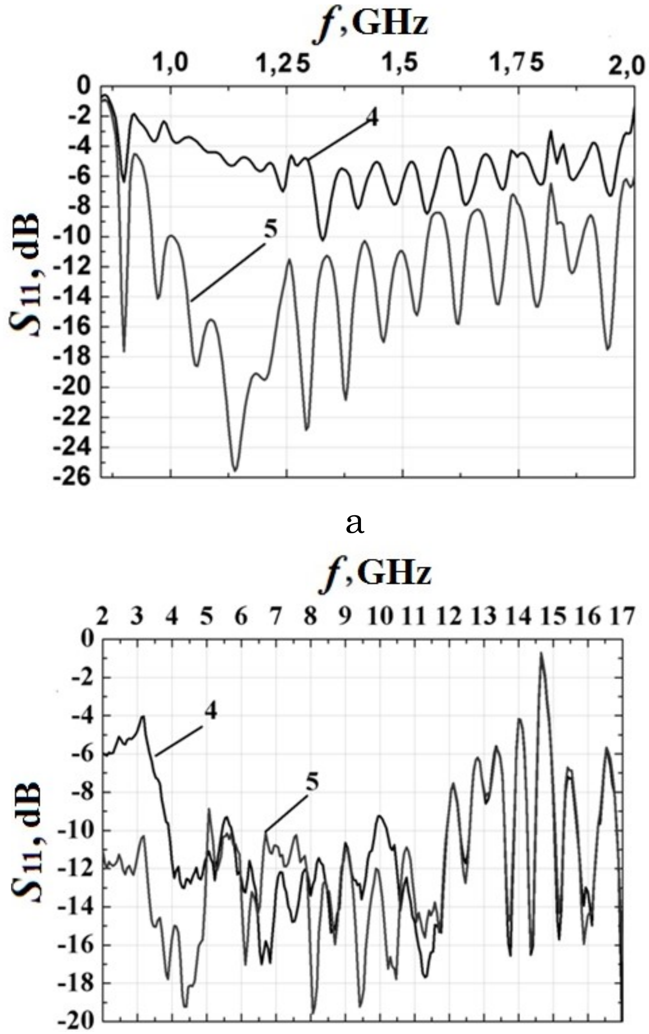
Figure 4.2 – Frequency dependences of EMR transmission coefficient in the range 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of electromagnetic shields samples of group 1:
4 – sample No. 4; 5 – sample No. 5



a

b

Figure 4.6 – Frequency dependences of EMR reflection coefficient in the range 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of electromagnetic shields samples of group 2 obtained as a result of measurements in mode 1: 4 – sample No. 4; 5 – sample No. 5



a

b

Figure 4.7 – Frequency dependences of EMR reflection coefficient in the range 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of electromagnetic shields samples of group 2 obtained as a result of measurements in mode 2: 4 – sample No. 4; 5 – sample No. 5

Based on the obtained results, it was found that the electromagnetic shields of group 2 with composite coal-containing coatings are characterized by EMR transmission and reflection coefficients values (mode 1) in the range of 0.7–2.0 GHz, varying respectively from –2.0 to –17.0 dB and from –4.0 to –22.0 dB (Figures 4.5, 4.6). Moreover, the composition of these coatings doesn't significantly affect the values of the considered parameters (they change by no more than 2 dB as a result of changes in the composition of the coating).

With an increase in the frequency in the range of 2.0–17.0 GHz, a decrease of EMR transmission coefficient values from –2.0 to –10.0 dB is observed for electromagnetic shields of group 2 with combined coatings. For shields coated with powdered charcoal, EMR transmission coefficient values in the frequency range vary from –6.0 to –14.0 dB.

EMR reflection coefficient values of electromagnetic shields of group 2, measured in the mode 2, in the frequency range 0.7–5.0 GHz, substantially depend on the composition of the composite coal-containing coatings used for the manufacture of these shields (Figure 4.7). So, the value of the considered parameter for shields with coatings based on powdered charcoal varies from –8.0 to –26.0 dB, and for shields with combined coatings – from –2.0 to –10.0 dB. In the frequency range 5.0–17.0 GHz, EMR reflection coefficient values of electromagnetic shields of group 2, measured in the mode 2, don't depend on the composition of the composite coatings used for the manufacture of these shields, and vary from –4.0 to –20.0 dB. This is due to the fact that in the indicated frequency range, most of the electromagnetic waves are scattered not by geometric heterogeneities of the surfaces of the shields of group 2, but are not absorbed by composite coal-containing coatings of these shields.

Thus, by adding powdered titanium dioxide to the composition of composite coal-containing coatings, it is possible to reduce by 3.0–10.0 dB EMR reflection coefficient (mode 2) in the frequency range 0.7–17 GHz of electromagnetic shields with a flat surface based on them. By changing the surface structure of electromagnetic shields with composite coal-containing coatings, it is possible to increase their average EMR shielding efficiency by 10 dB [111].

The obtained results allow to recommend the developed methodology for forming finishing panels for electromagnetic shielding of microwave sources and ensuring environmental protection for staff, providing the service of personal computers and industrial plants.

## 4.2 Flammable Electromagnetic Shields Based on Coatings with Coal-Containing Materials

One of the varieties of measures taken to ensure the stable operation of electronic equipment is the electromagnetic shielding of the rooms where this equipment is located. The electromagnetic shields used for this should be characterized by a low mass per unit area and a small value of EMR reflection coefficient. In addition, when developing devices designed for electromagnetic shielding of rooms, it is necessary to take into account the conditions under which the required level of fire safety will be provided for such rooms. This is done when the elements of building structures of shielded rooms are characterized by the property of low flammability or fire resistance.

The paper [39] presents the results of creating fire-resistant electromagnetic shields based on powdered schungite, which ensures the energy loss of EMR interacting with it due to the fact that it is a carbon-containing material and is characterized by high values of specific conductivity (0.2–1.5 Sm/cm, depending from the volume of impurities contained in it) [112]. The main disadvantage of such shields is their significant cost, due to the low prevalence of schungite rock deposits, as well as the complexity of the processes associated with its production and processing [113]. In this regard, it seems relevant to search for carbon-containing materials, characterized by a reduced cost, compared with powdered shungite. Such materials may include charcoal and activated carbon, which is a product of wood combustion, as well as carbon black (soot), which is a waste of thermal decomposition of hydrocarbons [114].

The methodology for the manufacture of electromagnetic shields based on these materials was proposed, the study results of the laws of interaction of electromagnetic radiation in the frequency range 0.7–17 GHz with such shields were presented, and an experimental substantiation of their low flammability was performed. Shields made in accordance with the proposed methodology are three-layer structures. The first (surface) layer of such structures is a composite material based on the powdered carbon-containing filler. The second layer is a canvas of carbon-containing fabric made in accordance with the technology described in the paper [115]. The advantages of such fabric are its low mass per unit area (0.25 kg/m$^2$), as well as the fact that it provides the energy loss of the EMR interacting with it (the value of its EMR transmission coefficient in the frequency range 0.7–17.0 GHz varies from –5.0 to –10.0 dB). The third layer of the proposed shield is foil polyethylene. The implementation of electromagnetic shield in the form of multilayer structures helps to reduce their EMR reflection coefficient values (compared with single-layer shields).

The methodology for the manufacture of screens includes the following steps.

*Step* 1. Cut the canvases of carbon-containing fabric and foil polyethylene into fragments of the required sizes and shapes, which are determined by the overall parameters of the building structures of the shielded rooms.

*Step* 2. Fixing the fragments of carbon-containing fabric on the surface of fragments of foil polyethylene by adhesive or thread bonding.

*Step* 3. Preparation of filler for a composite material designed to form a surface layer of a synthesized shield. It consists in grinding to a powder state briquettes of charcoal or granules of activated carbon using a drum-ball mill. The degree of grinding is 10 microns.

*Step* 4. Obtaining a composite material intended for the formation of the surface layer of the synthesized shield. It is performed by uniformly distributing the powdered carbon-containing filler (charcola and activated carbon, carbon black) over the volume of the binder in the liquid phase. This must be implemented using an industrial mixer. It is proposed to use "AgniTerm" WDC as a binder. The volume ratio of filler and binder in the composite material is 1:3. It was established experimentally that an increase (compared with the indicated values) of the volume content of the filler in the binder leads to the destruction of the synthesized composite material during its drying, and a decrease leads to an increase its EMR transmission coefficient in the frequency range 0.7–17.0 GHz.

*Step* 5. Application of the obtained composite material to the surface of fragments of carbon-containing fabric, connected in stage 2 with fragments of foil polyethylene. This process must be implemented with a spatula.

*Step* 6. Drying of the obtained electromagnetic shields under the normal conditions.

In accordance with the proposed methodology electromagnetic shields samples were made. The number of the samples types made is 3. The samples of each of the types differed in the kind of the powdered carbon-containing filler included in their surface layer (charcoal in sample No. 1, activated carbon and carbon black in samples No. 2 and No. 3, respectively).

EMR transmission coefficient values in the frequency range 0.7–17.0 GHz of electromagnetic shields manufactured in accordance with the proposed method vary from –15.0 to –40.0 dB, regardless of the type of powdered filler of the composite material used to form their surface layer. This is due to the presence of foil material in the composition of the shield (third layer).

The frequency dependences of the EMR reflection coefficient in the range of 0.7–17.0 GHz of manufactured shields samples obtained as a result of measurements in the mode 2 are presented in Figure 4.8.

It follows from Figure 4.8 that the smallest average value of EMR reflection coefficient in the frequency range 0.7–17.0 GHz corresponds to the electromagnetic shield based on activated carbon (sample No. 2), the largest – to electromagnetic shield based on charcoal (sample No. 1). The value of the considered parameter for the first of these shields is –8.0 dB, for the second –5.0 dB. This is due to the fact that the powdered filler of the composite material used to form the surface layer of the sample No. 1 is characterized by a higher content of carbon compounds compared with the fillers of the surface layers materials of the samples No. 2 and No. 3. This is confirmed by the results of their X-ray diffraction analysis (Figure 4.9).

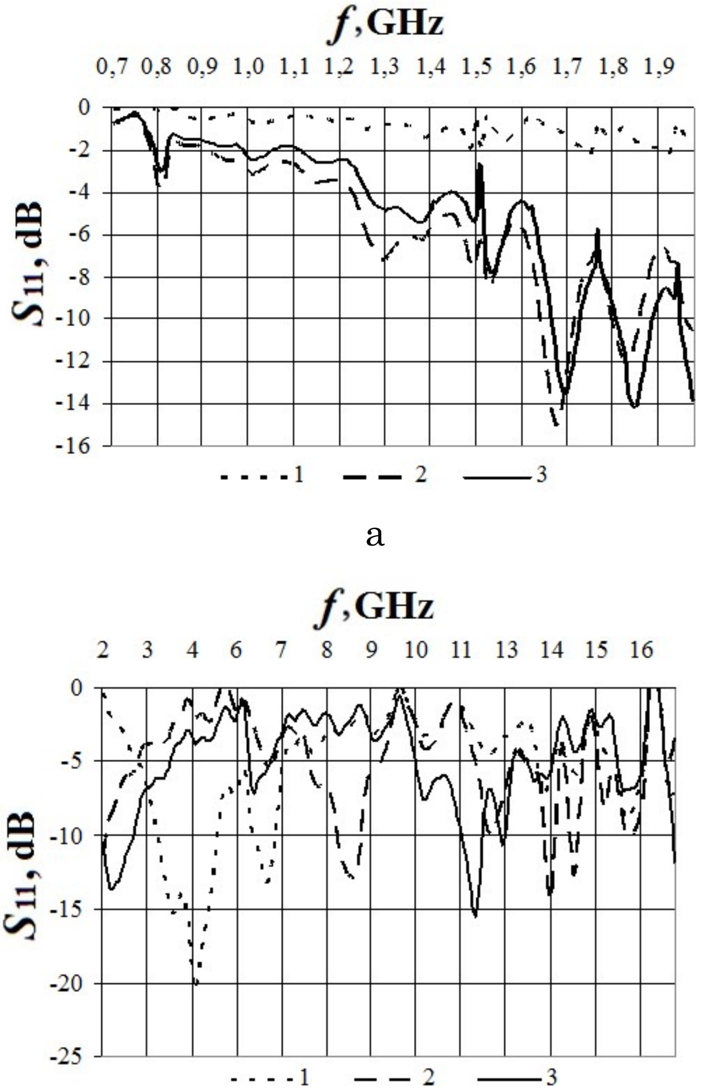


Figure 4.8 – Frequency dependences of EMR reflection coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of the studied shields samples: 1 – sample No. 1; 2 – sample No. 2; 3 – sample No. 3

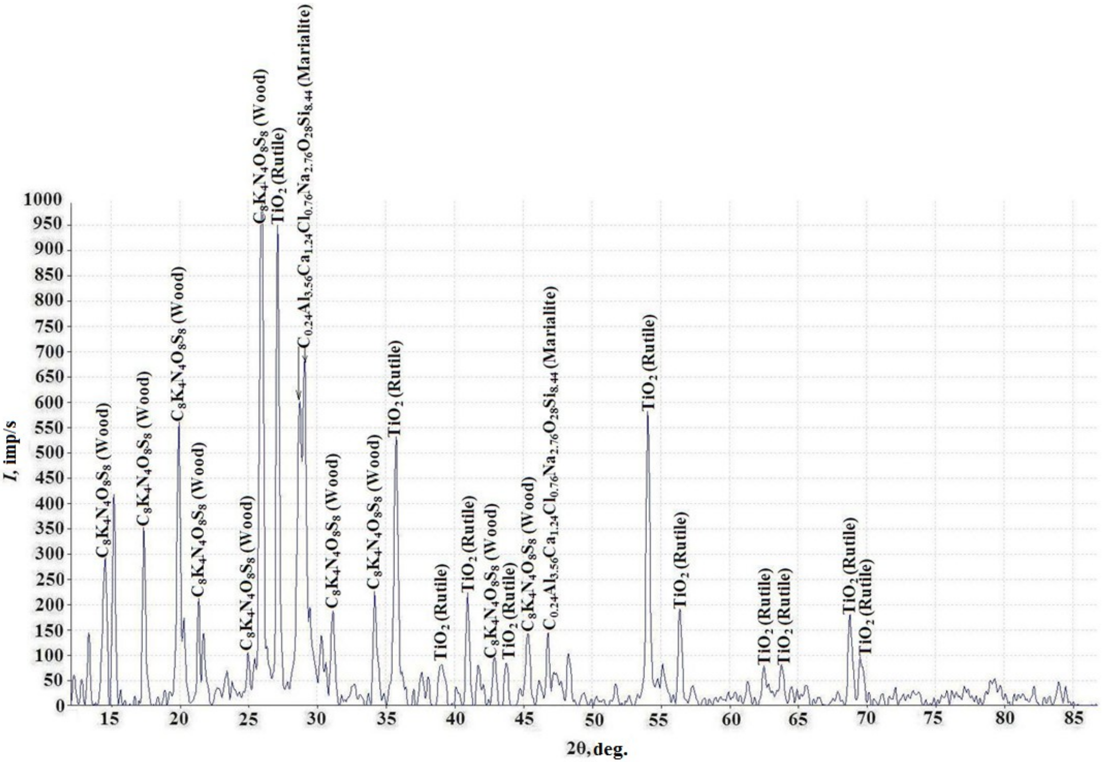


Figure 4.9 – Diffraction patterns of the composite material, used for forming of the sample No. 1 surface layer

It was established that the composition of the composite material used to form the sample No. 1 surface layer includes 50.9 mass. % wood ($C_8K_4N_4O_8S_8$), 34.7 wt. % of the marialite ($C_{0,24}Al_{3,}56Ca_{1,24}Cl_{0,76}Na_{2,76}O_{28}Si_{8,44}$) and 14.4 wt. % of the rutile ($TiO_2$).

The composite material used to form the sample No. 2 surface layer includes 38.1 wt. % of carbon compound $C_4ClN_4S_4$, 29,7 wt. % of the rutile ($TiO_2$), 28 wt. % of the megacalsilite ($AlKO_4Si$) and 4,2 wt. % of the $CO_5Pb_3$. The composition of the material of the sample No. 3surface layer includes 72.3 wt. % of pentachlorophenyl disulfide ($C_{12}Cl_{10}S_2$), 24.1 wt. % of the rutile ($TiO_2$) and 2.5 wt. % of the dichlorobis platinum ($C_4H_{12}Cl_2PtS_2$).

It was determined that the type of powdered filler used to form the samples surface layer affects the value of the resonant frequencies of their EMR reflection characteristics in the range 2.0–17.0 GHz. In particular, the minimum value of EMR reflection characteristic of sample No. 1 was –20.0 dB and was recorded at a frequency of 4.0 GHz. For similar characteristics of samples No. 2 and No. 3, the minimum value was –15.0 dB at frequencies

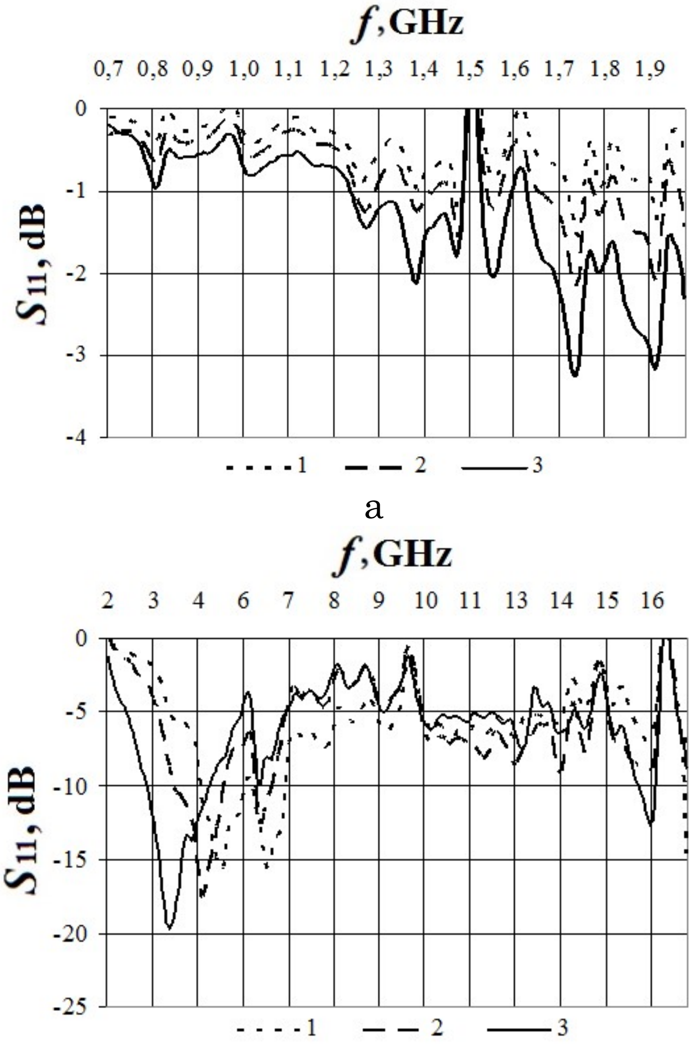
14.0 and 12.0 GHz respectively. This phenomenon is due to the mechanisms of EMR interaction with the material of the studied samples surface layers. These mechanisms depend on the specific conductivity of these materials, which is determined by the carbon percentage in them.

Based on the results of testing the electromagnetic shields samples for flammability, it was established that they belong to the class of hardly flammable, since in the process of exposure to an open flame, smoldering and carbonization of the material of their surface are observed, which cease upon completion of such exposure. At the same time, cracks, delaminations or other types of destruction are not formed on the shields surface.

The regularities of EMR of the frequency range 0.7–17.0 GHz interaction with electromagnetic shields samples after exposure to an open flame are investigated. The results of such study are systematized into graphical dependencies presented in Figure 4.10.

It was established that as a result of heat treatment with an open flame of the studied shields, the values of their EMR reflection coefficient in the frequency range 0.7–17.0 GHz increase by 0.5–10.0 dB.

In addition, the considered parameter value of the shields subjected to heat treatment doesn’t substantially depend on the type of powdered carbon-containing filler of the composite materials used to form their surface layer. This is due to the similarity of the compositions of the materials formed as a result of exposure to these composite materials with an open flame, which is confirmed by the results of their X-ray diffraction analysis (Figure 4.11).



a

b

Figure 4.10 – Frequency dependences of EMR reflection coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of the studied shields samples after their heat treatment with an open flame: 1 – sample No. 1; 2 – sample No. 2; 3 – sample No. 3

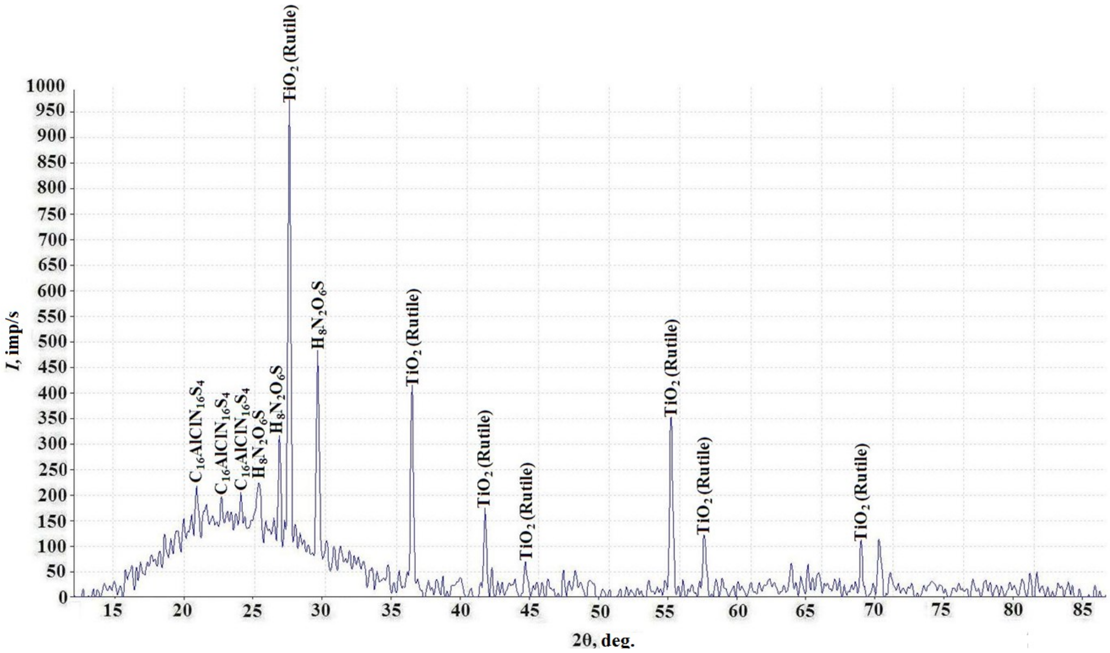


Figure 4.11 – Diffraction pattern of the surface layer material of the screen samples after their heat treatment with an open flame

It was established that after heat treatment with the open flame of the studied shields, the main component of the composite materials used to form their surface layer is rutile ($TiO_2$). The content of carbon compounds in such materials as a result of the implementation of this process is reduced, which leads to a decrease in the energy loss of EMR interacting with them and, as a result, an increase of EMR reflection coefficient of electromagnetic shields based on these materials. EMR transmission coefficient values of the studied shields after their heat treatment with an open flame don't change significantly.

Based on the obtained results, it can be concluded that the proposed electromagnetic shields are acceptable for use as elements of load-bearing or enclosing structures in rooms where electronic equipment is located that is subject to protection from electromagnetic interference. This is due to the fact that such constructions provide a reduction by at least 10 times of EMR power, their surface doesn't degrade during interaction with an open flame. In addition, the implementation of the proposed shields in the form of multi-layer construction helps to prevent the creation of passive electromagnetic interference due to the propagation of electromagnetic waves within the shielded rooms that are reflected from the metal elements of their building structures. Compared with the shields based on powdered schungite, the proposed construction are characterized by a reduced mass due to the fact that the bulk density of powdered charcoal and activated carbon, as well as carbon black, is at least 20 % lower than that of powdered schungite (with comparable sizes of fractions specified materials) [116, 117].

## 4.3 Modular Constructions of Electromagnetic Shields based on Powdered Carbon and Coal materials

### 4.3.1 Flexible Constructions of Electromagnetic Shields Based on Powdered Coal and Carbon Black

There are known the constructions of electromagnetic shields made by filling of various forms with powder materials that are characterized by dielectric, magnetic or resistive properties. [118]. Compared with the constructions of the shields based on powdered materials obtained by fixing powdered materials in various colloidal binders or by sintering such materials, the production of known constructions requires little time. However, such screens are characterized by considerable mass and rigidity, which is associated with the properties of the forms used for their manufacture.

In the laboratory “Materials and elements of electronic and superconducting technology” of R&D Department of the Educational Institution “Belarusian State University of Informatics and Radioelectronics” the methodology for the manufacture of flexible constructions of electromagnetic shields based on powdered materials that are characterized by dielectric, magnetic or resistive properties is proposed [119]. The methodology is based on the use of special film containers as molds for filling with the indicated materials. The manufacturing process of flexible electromagnetic shields in accordance with the proposed methodology consists in sequential filling of special organic films and their subsequent local heat treatment (sealing of containers filled with a powdery mass).

It was experimentally established that the proposed method cannot be used for the manufacture of flexible designs of electromagnetic shields based on powdered coal and coal-containing materials, which is due to difficulties in realizing the sealing of containers filled with such materials (particles of the powdered coal and coal-containing materials settle on the inner walls of the containers and degrade their adhesive properties).

In this regard, a new methodology has been proposed for the formation of flexible designs of electromagnetic shields based on powdered coal-containing materials. [120]. It includes the following steps (Figure 4.12).

*Step* 1. Filling with a powdery carbon-containing material of zip-lock plastic bags, the size of which is 5×5 cm.

*Step* 2. Fixing the fragments of double-sided adhesive tape on the surface of the canvas of polyester thermoplastic film in accordance with a specific scheme.

*Step* 3. Fixing plastic bags filled with powdered coal-containing material on the surface of a polyester-polyethylene film web by placing them on fragments of double-sided adhesive tape.

*Step* 4. Laying on top of plastic bags canvas polyester-polyethylene thermofilm.

*Step* 5. The connection of the canvas of polyester-polyethylene thermofilm, on which polyethylene bags filled with powder material are fixed, with the canvas of the polyester-polyethylene thermofilm located on top of these packets, by sealing them along conditional longitudinal parallel and transverse parallel lines. These conditional lines are located between rows of plastic bags filled with powdered coal-containing material.

It was found that the weight of 1 $m_2$ of flexible constructions of electromagnetic shields made in accordance with the proposed methodology is not more than 1.2 kg (depending on the type of the used powdered coal material).

In accordance with the proposed methodology the electromagnetic shields constructions samples based on powdered coal and carbon materials were made. Samples No. 1 and No. 2 were made on the basis of powdered charcoal and activated carbon, sample No. 3 – on the basis of carbon black.

The frequency dependences of EMR transmission and reflection coefficients in the range 0.7–17.0 GHz of sample No. 1 are presented in Figures 4.13–4.15.

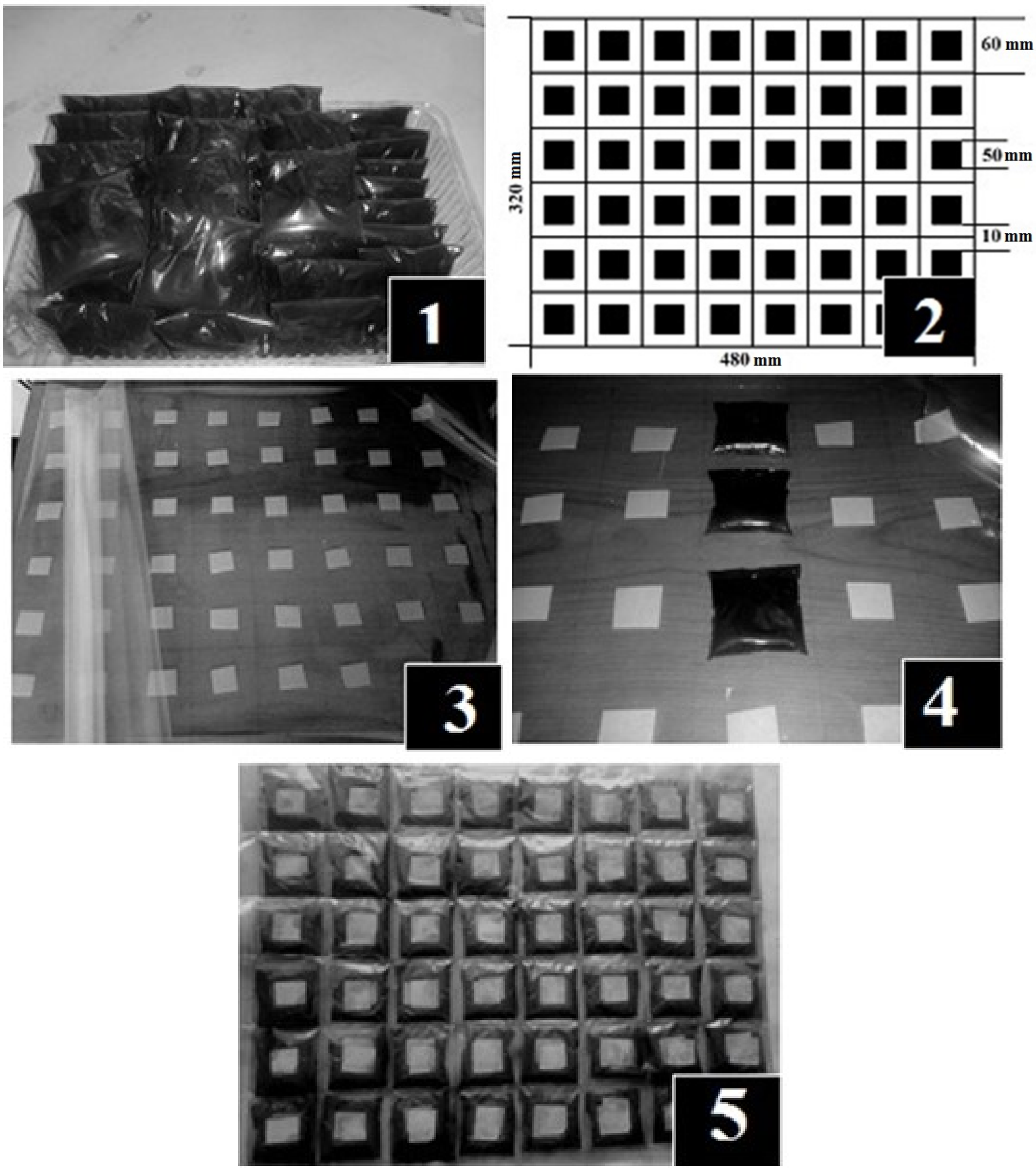
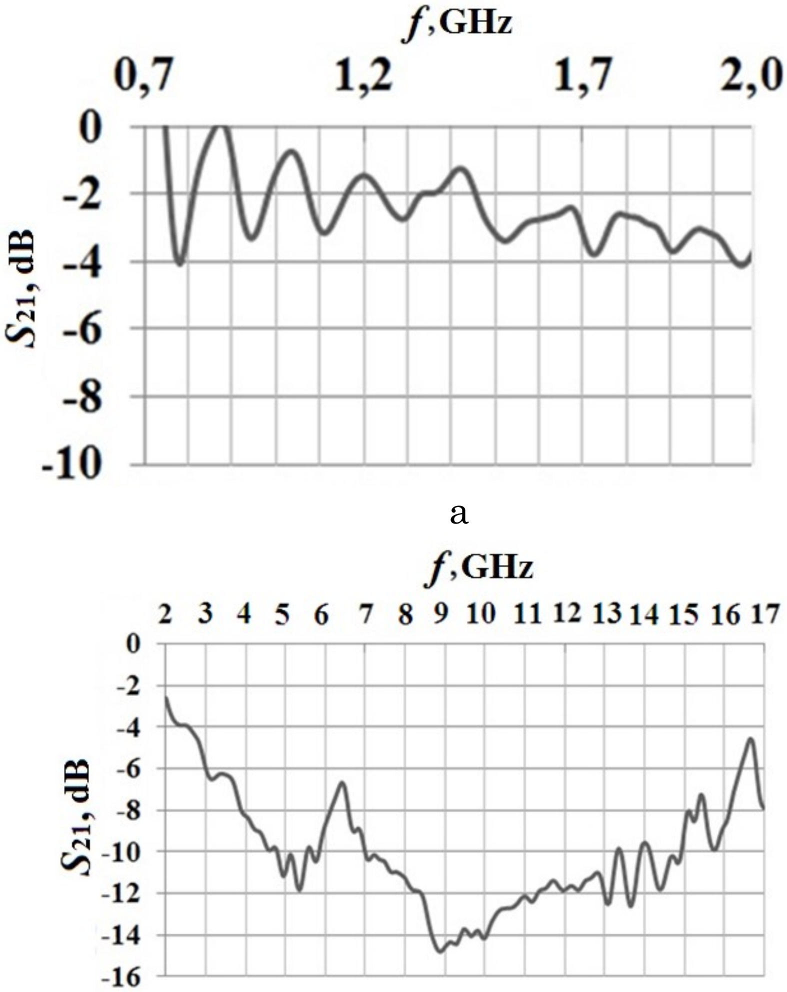


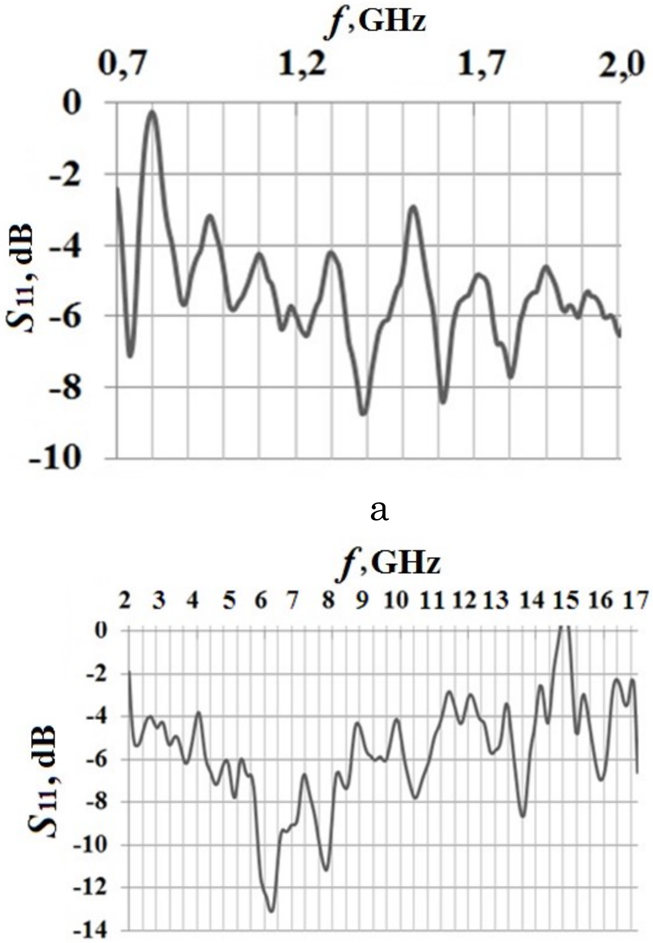
Figure 4.12 – Illustration of the stages and schemes for the formation of flexible constructions of electromagnetic shields based on powdered coal-containing materials: 1 – the result of the stage 1 implementation; 2 – the placement scheme of the plastic bags filled with powdered coal-containing material on the surface of the polyester-polyethylene thermofilm canvas (for stage 2); 3 – the result of the implementation of the stage 2; 4 – the intermediate result of the implementation of the stage 3; 5 – the appearance of the flexible construction of electromagnetic shield sample



a

b

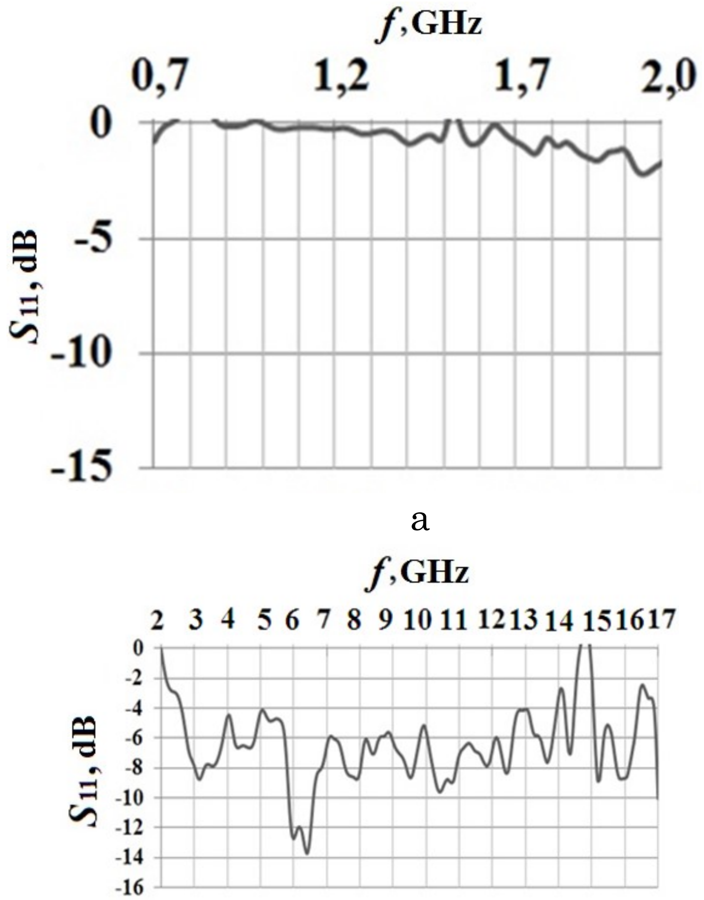
Figure 4.13 – Frequency dependences of EMR transmission coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of sample No. 1



a

b

Figure 4.14 – Frequency dependences of EMR reflection coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of sample No. 1, obtained as a result of measurements in mode 1



a

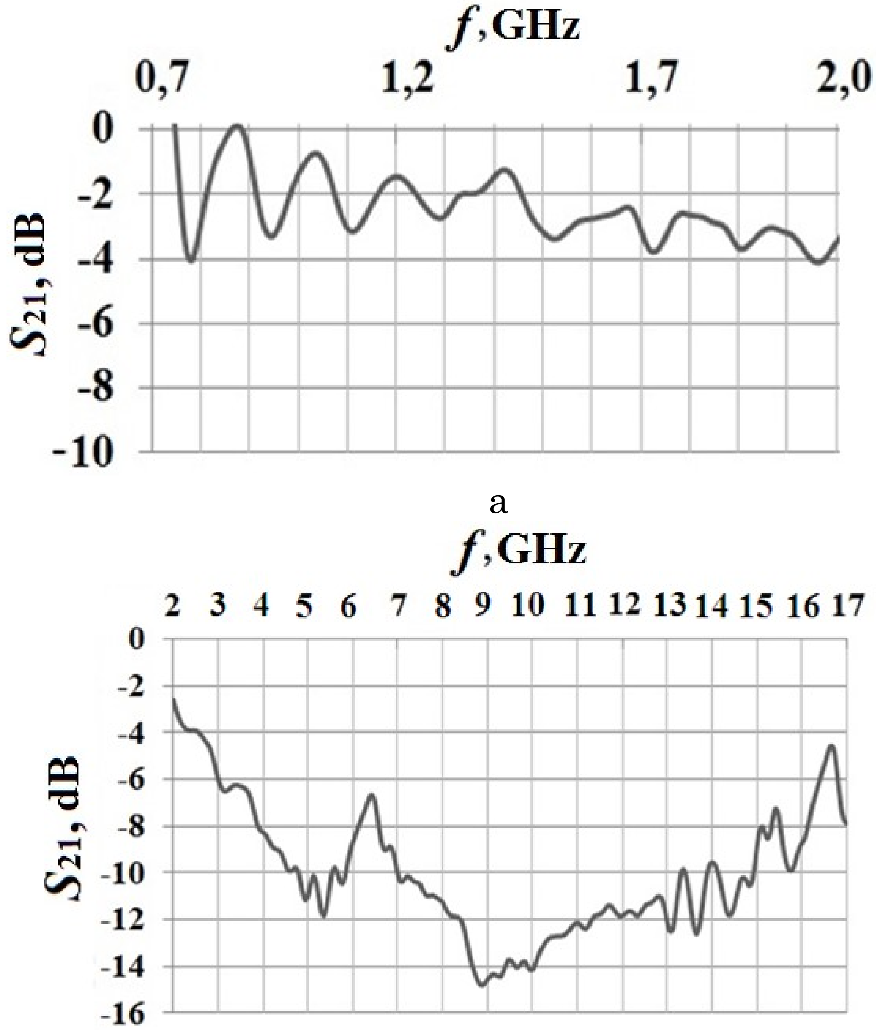
b

Figure 4.15 – Frequency dependences of EMR reflection coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of sample No. 1, obtained as a result of measurements in mode 2

It was established that flexible constructions of electromagnetic shields based on powdered charcoal are characterized by EMR transmission coefficient values varying from –0.5 to 1.0 dB in the frequency range 0.7–2.0 GHz (see Figure 4.13, a). The average value of EMR reflection coefficient in the indicated frequency range, measured in mode 1, is –5.0 dB (see Figure 4.14, a), and in mode 2 is –1.0 dB (see Figure 4.15, a).

In the frequency range 2.0–17.0 GHz, a decrease of EMR transmission coefficient to the value of –3.0 dB was observed (Figure 4.13, b). The average value of EMR reflection coefficient in the indicated frequency range, measured in modes 1 and 2, is –7.0 dB (Figure 4.14, b and Figure 4.15, b) [121].

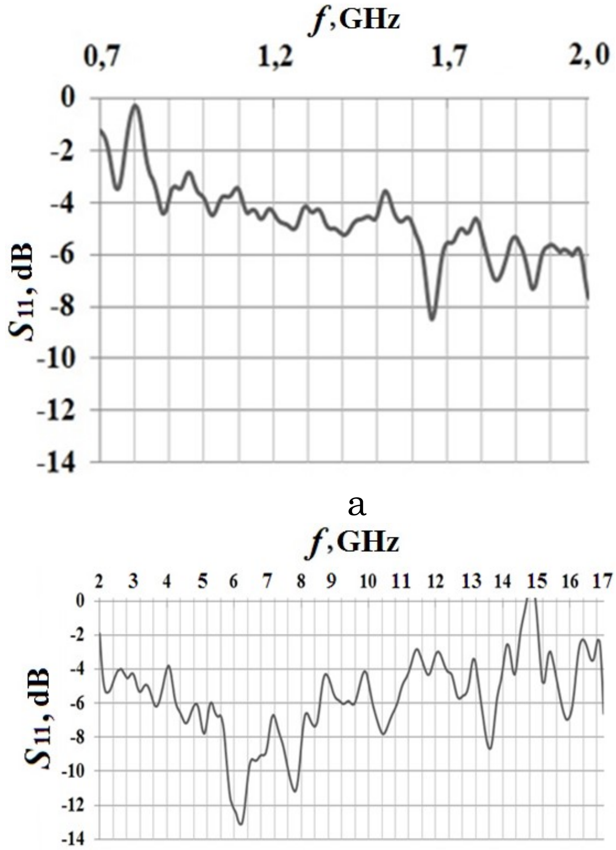
The frequency dependences of EMR transmission and reflection coefficients in the range 0.7–17.0 GHz of sample No. 2 are presented in Figures 4.16–4.18.



a

b

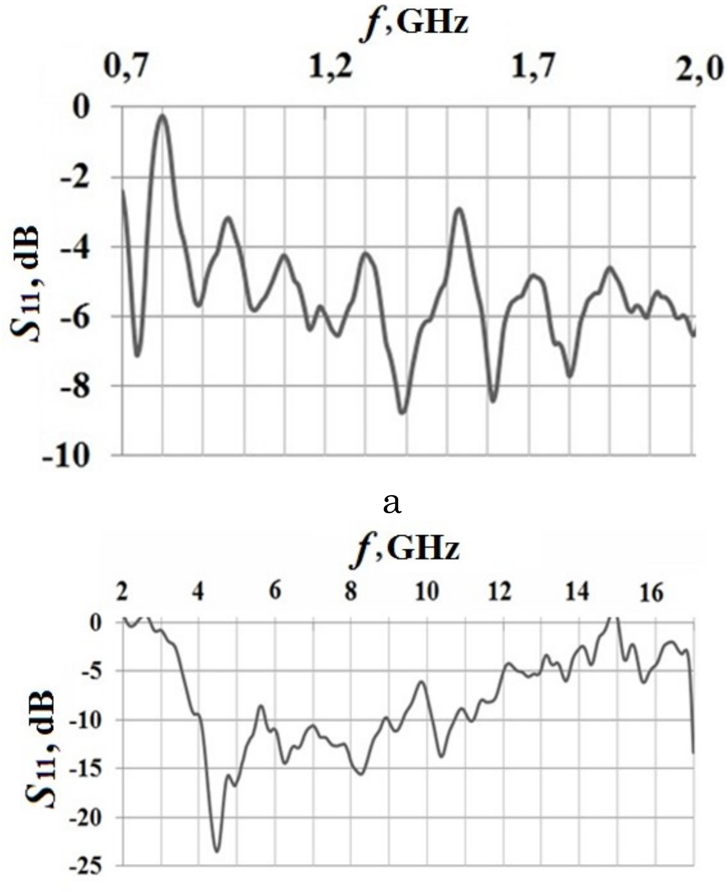
Figure 4.16 – Frequency dependences of EMR transmission coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of sample No. 2



a

b

Figure 4.17 – Frequency dependences of EMR reflection coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of sample No. 2, obtained as a result of measurements in mode 1



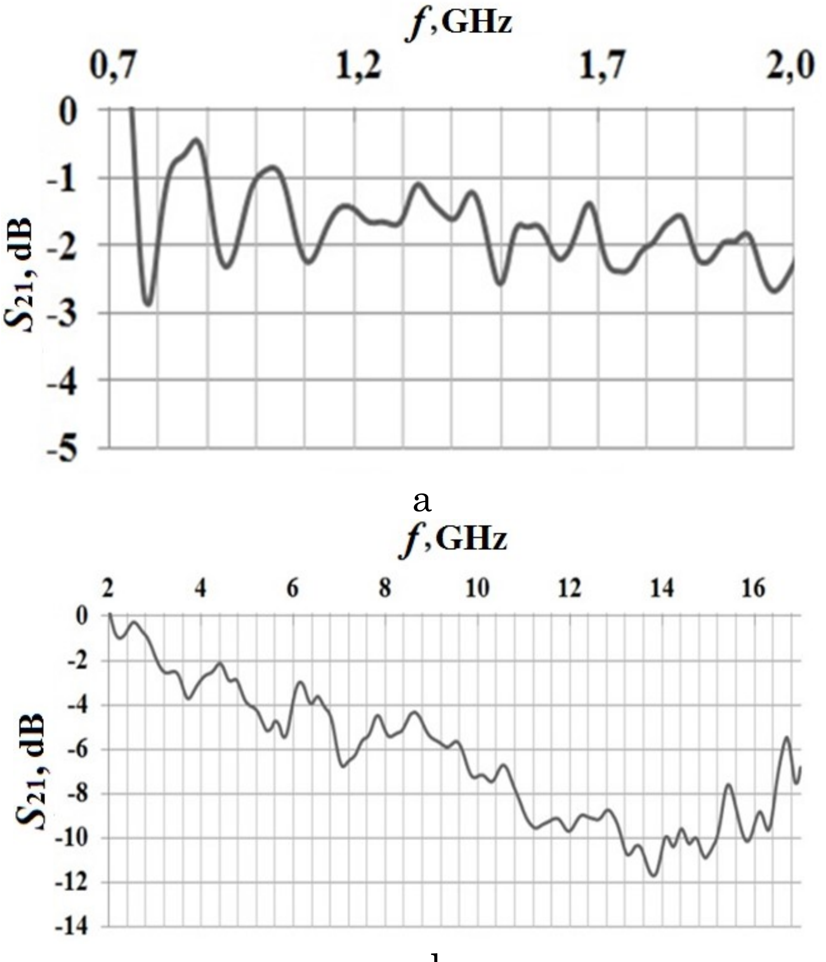
a

b

Figure 4.18 – Frequency dependences of EMR reflection coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of sample No. 2, obtained as a result of measurements in mode 2

It follows from Figure 4.16 that EMR transmission coefficient values of flexible constructions of electromagnetic shields based on powdered activated coal vary from –0.5 to –4.0 dB in the frequency range 0.7–2.0 GHz and from –3.0 to –15.0 dB in the frequency range 2.0–17.0 GHz. EMR reflection coefficient values of the considered shields in the indicated ranges, measured in mode 1, vary respectively from –0.5 to –8.0 dB and from –0.5 to –13.0 dB (see Figure 4.17). In the frequency range 0.7–2.0 GHz, 12.0–17.0 GHz, EMR reflection coefficient values of the considered shields obtained as a result of measurement in mode 2 are similar to those obtained as a result of measurement in mode 1. In the frequency range 2.0–3.0 GHz, the first values are less on 2.0–4.0 dB than the second ones, and in the frequency range 3.0–12.0 GHz it is more on 2.0–15.0 dB. EMR reflection characteristic of the considered shields in the frequency range 2.0–17.0 GHz has a pronounced minimum point corresponding to the value of 4.5 GHz (see Figure 4.18, b).

The frequency dependences of EMR transmission and reflection coefficients in the range 0.7–17.0 GHz of sample No. 3 are presented in Figures 4.19–4.21.



a

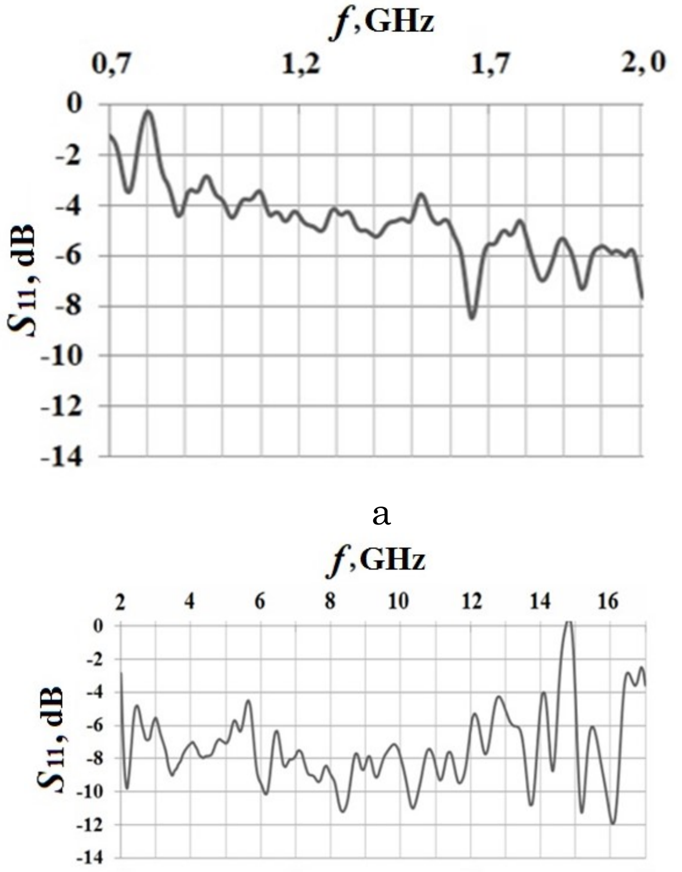
b

Figure 4.19 – Frequency dependences of EMR transmission coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of sample No. 3

It has been established that the flexible constructions of electromagnetic shield based on powdered carbon black is characterized by the EMR transmission and reflection coefficients values in the frequency range 0.7–17.0 GHz ranging from –0.5 to –12.0 dB.

EMR reflection coefficient values of the considered shields, measured in mode 2, exceed by 2.0–4.0 dB in the frequency range of 0.7–2.0 GHz the same parameter values measured in mode 1 (Figure 4.20, a and Figure 4.21, a).

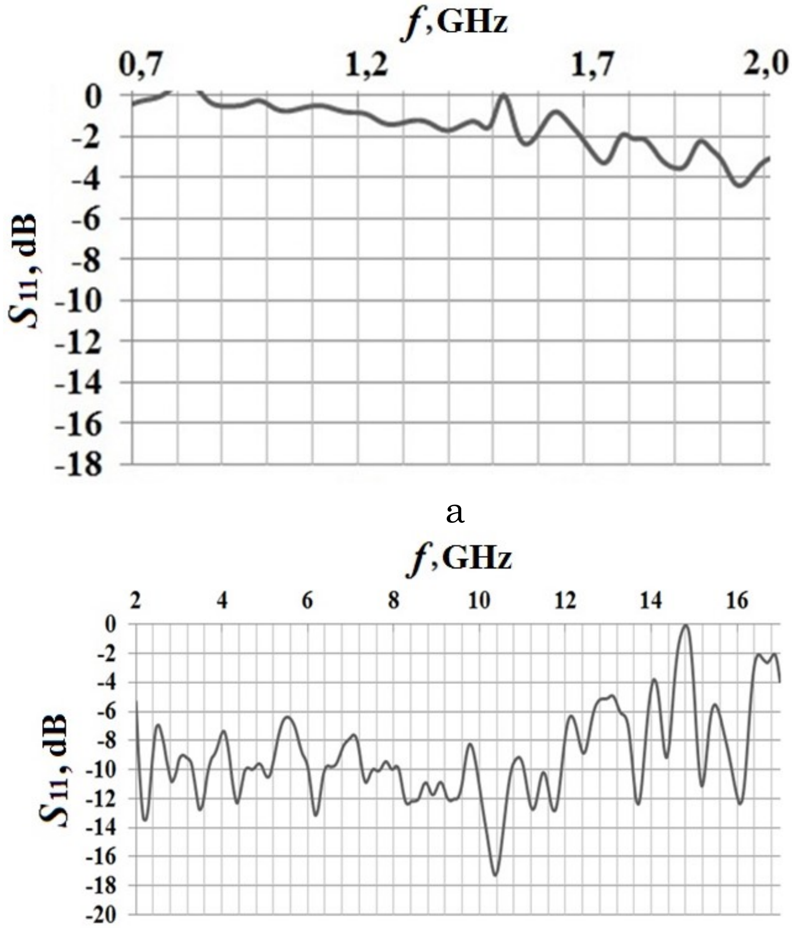
In the frequency range of 2.0–17.0 GHz, EMR reflection coefficient values of the considered shields don’t significantly depend on the measurement mode.



a

b

Figure 4.20 – Frequency dependences of EMR reflection coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of sample No. 3, obtained as a result of measurements in mode 1



a

b

Figure 4.21 – Frequency dependences of EMR reflection coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of sample No. 3, obtained as a result of measurements in mode 2

An increase in the overall of EMR shielding efficiency by the developed flexible constructions of electromagnetic shields was achieved by reducing their EMR reflection coefficient, which is associated with additional scattering of incident electromagnetic waves by the active surface of such constructions, which is geometrically inhomogeneous. When falling on such a surface, electromagnetic waves are reflected many times and lose much more energy than when they fall on a homogeneous surface.

The obtained results allow to recommend using the formed constructions for electromagnetic shielding of computer equipment used to process information of limited distribution.

In accordance with the methodology presented in Section 2.6, it is established that such designs provide a reduction of at least in 2 times the radius of the controlled zone of SEMR from computer equipment (Figure 4.22).

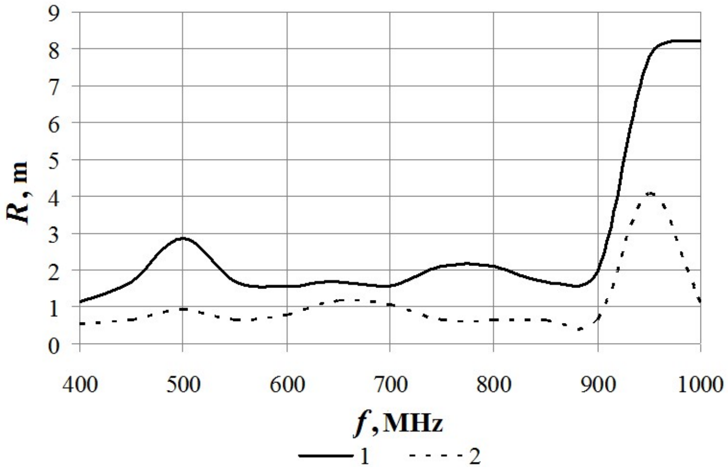


Figure 4.22 – Frequency dependences of the radius of the controlled zone of SEMR of the computer equipment: 1 – the computer equipment is not shielded; 2 – the computer equipment is shielded using a flexible panel based on powdered charcoal

### 4.3.2 Flexible Panels Based on Powdered Coal-Containing Materials for Architectural Electromagnetic Shielding

The proposed panels based on powdered coal-containing materials for architectural electromagnetic shielding include the following components:

– polyurethane foam plates with a thickness of 2 mm;

– polyethylene mesh with a thickness of 0.1 cm and a cell size of 0.5×0.5 cm;

– aluminum film sealed with a plastic film (total thickness – 0.05 cm);

– polyester carbon-containing fabric with a thickness of 0.6 cm (carbon content is up to 10 vol. %);

– polyethylene terephthalate thermofilm with thickness of 0.3 mm;

– powdered charcoal with a particle size of 0.7 mm or less;

– powdered titanium dioxide with a particle size of ~ 10 μm;

– water-based filler based on a $CaCl_2$ solution.

The methodology for manufacturing the flexible panels based on powdered charcoal for architectural electromagnetic shielding includes the following steps.

*Step* 1. Cutting polyurethane foam plates and polyethylene mesh into fragments. The cutting of these materials should be performed according to the patterns, formed taking into account the geometric dimensions of the architectural elements on which it is supposed to fix the manufactured structure.

*Step* 2. Cutting an aluminum film into fragments whose length and width do not exceed 1 cm.

*Step* 3. Production of $CaCl_2$ water solution with the concentration of 45 mass. %

*Step* 4. Impregnation of the manufactured water solution of powdered charcoal.

*Step* 5. Placing a fragment of a polyethylene mesh on a fragment of a polyurethane foam plate.

*Step* 6. Application of a water-containing powdered charcoal on a fragment of a polyethylene mesh placed on a fragment of a polyurethane foam plate. The thickness of the layer of applied material is no more than 1 cm.

*Step* 7. Placing a fragment of a polyethylene mesh on a layer of water-containing powdered charcoal.

*Step* 8. Uniform distribution of aluminum film fragments obtained as a result of the step 2 implementation, on a polyethylene mesh fragment placed on top of a layer of water-containing powdered charcoal.

*Step* 9. Placing a polyurethane foam fragment plate on top of aluminum film fragments.

*Step* 10. Pressurization the obtained structure by means of polyethylene terephthalate thermofilm using the sealing method [122].

The methodology for manufacturing of flexible panels based on a mixture of powdered charcoal and titanium dioxide for electromagnetic protection of rooms includes the following steps.

*Step* 1. Cutting a polyester carbon-containing fabric and polyethylene mesh into fragments according to the patterns.

*Step* 2. Cutting an aluminum film into fragments whose length and width do not exceed 1 cm.

*Step* 3. Production of $CaCl_2$ water solution with the concentration of 45 wt. %

*Step* 4. Mixing powdered charcoal and titanium dioxide in a volume ratio of 1: 1.

*Step* 5. Impregnation with the prepared water solution of a mixture of powdered charcoal and titanium dioxide.

*Step* 6. Placing a polyethylene mesh fragment on a polyurethane foam plate fragment.

*Step* 7. Application of a water-containing mixture of powdered charcoal and titanium dioxide on a polyethylene mesh fragment placed on a polyurethane foam plate fragment. The thickness of the layer of applied material is not more than 1 cm.

*Step* 8. Uniform distribution of aluminum film fragments obtained as a result of the stage 2 implementation over the surface of a layer of a mixture of powdered charcoal and titanium dioxide.

*Step* 9. Placing a polyethylene mesh fragment on a layer of a moisture-containing mixture of powdered charcoal and titanium dioxide.

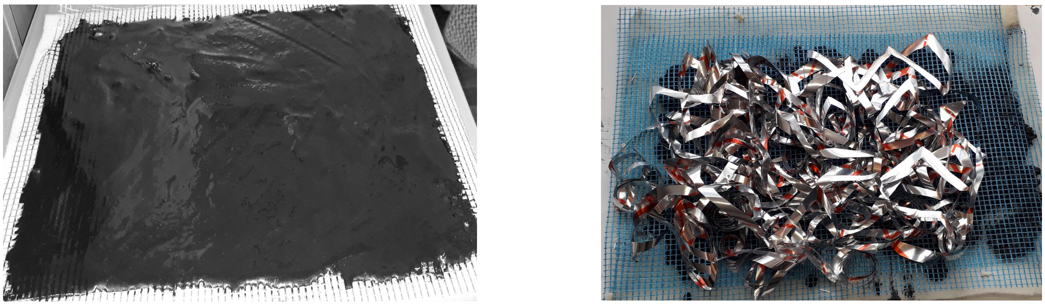
*Step* 10. Placing a polyurethane foam plate fragment on top of a polyethylene mesh fragment.

*Step* 11. Sealing the resulting structure using polyethylene terephthalate thermofilm using the sealing method.

Fundamentally new in the proposed methods is the use of polyethylene meshes to hold a water-containing powdered material with a pasty consistency in the construction of the electromagnetic shield. The use of aluminum film fragments for the manufacture of flexible panels helps to reduce the values of their EMR transmission coefficient, and therefore, increase the shielding efficiency.

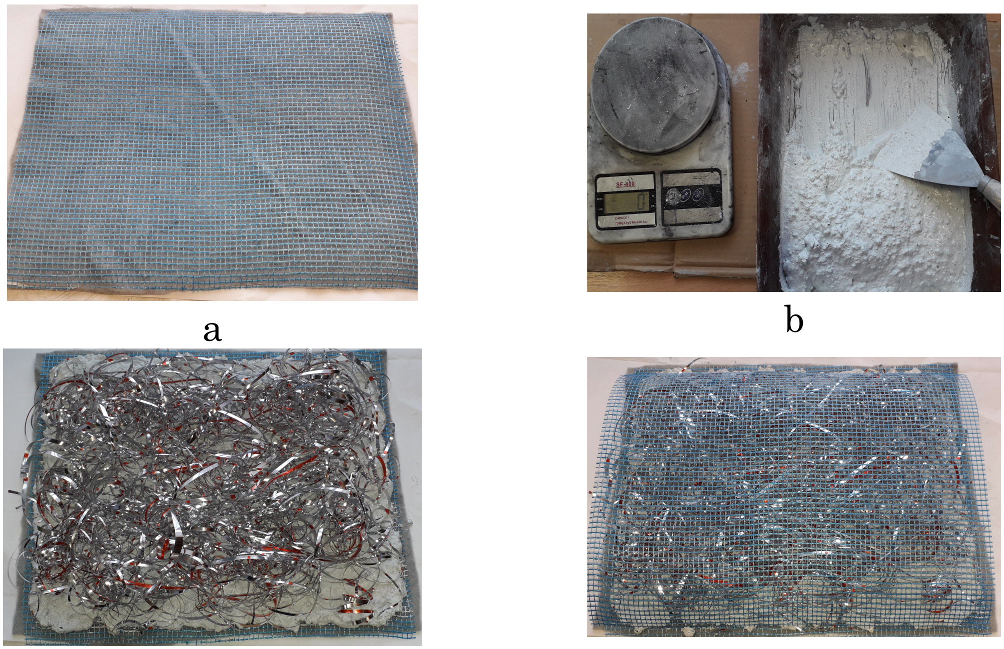
Figures 4.23, 4.24 show the appearance of panels manufactured according to the proposed methods for architectural electromagnetic shielding.

Figures 4.25, 4.26 show the frequency dependences of EMR transmission and reflection coefficients of panel samples made on the basis of water-containing powdered charcoal.



a b

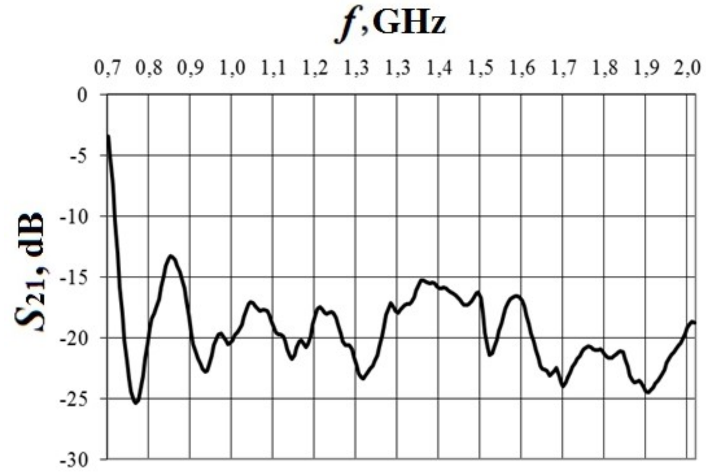
Figure 4.23 – Appearance of a panel for architectural electromagnetic shielding made on the basis of water-containing powdered charcoal: a – a layer based on moisture-containing charcoal located on the top of a polyethylene mesh fragments and a polyurethane foam plate; b – aluminum film fragments distributed over the surface of a polyethylene mesh fragment



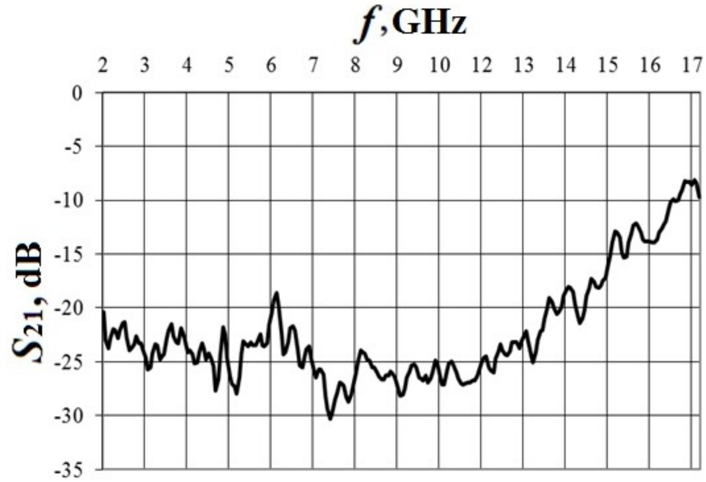
a b

c d

Figure 4.24 – Appearance of a panel based on a water-containing mixture of powdered charcoal and titanium dioxide for architectural electromagnetic shielding: a – polyethylene mesh fragment located on top of polyester carbon-containing fabric fragment; b –appearance of the water-containing mixture of powdered charcoal and titanium dioxide; c – aluminum film fragments distributed over the surface of the water-containing mixture of powdered charcoal and titanium dioxide; d –polyethylene mesh fragment placed on top of aluminum film fragments

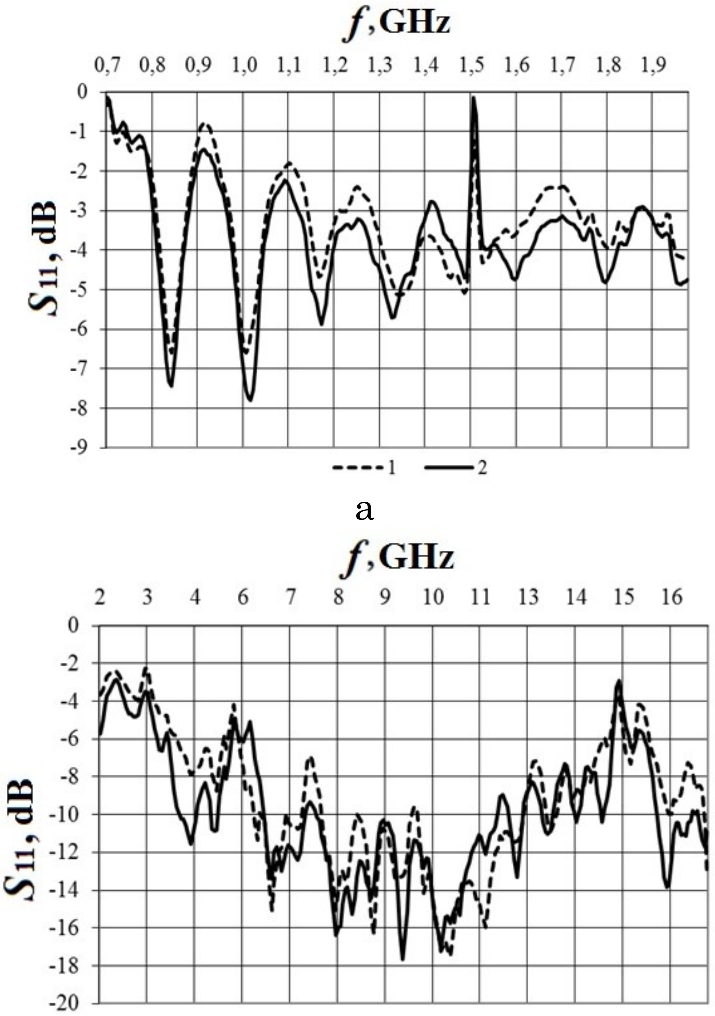


a



b

Figure 4.25 – Frequency dependences of EMR transmission coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of a panel sample based on water-containing powdered charcoal



a

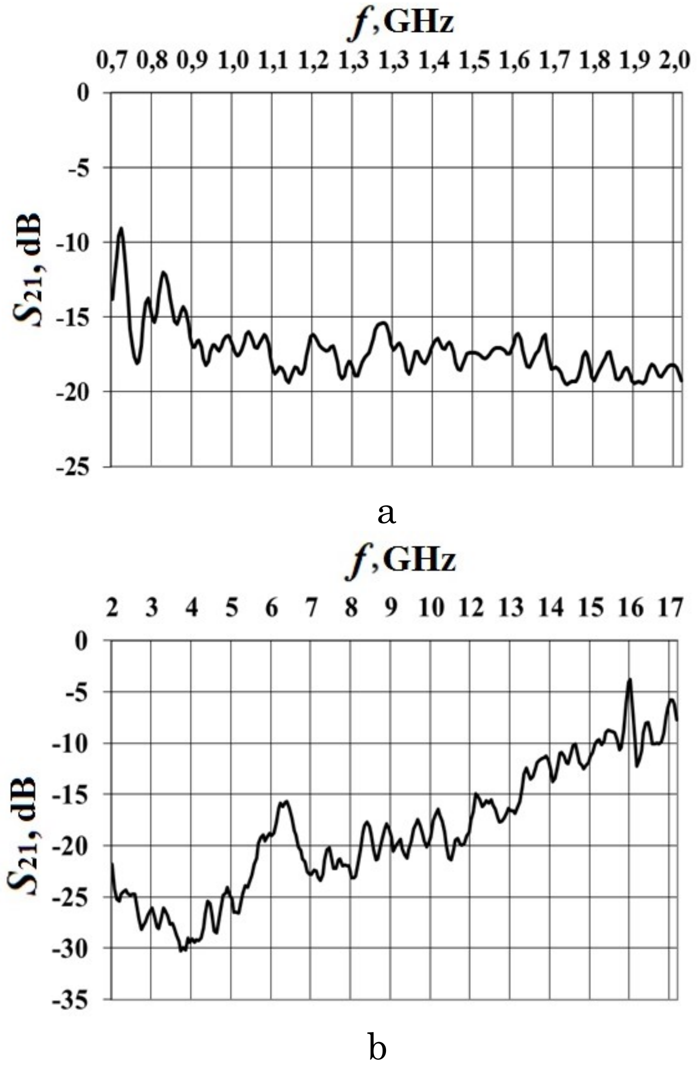
b

Figure 4.26 – Frequency dependences of EMR reflection coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of a panel sample based on water-containing powdered charcoal: 1 – frequency dependence obtained on the basis of the measurement results in mode 1; 2 – frequency dependence obtained on the basis of the measurement results in mode 2

It was found that EMR transmission coefficient values in the frequency range of 0.7–17.0 GHz for panels based on water-containing powdered charcoal vary from –10.0 to –30.0 dB. It was determined that the use of aluminum film fragments, the length and width of which does not exceed 1 cm, as part of a panel based on water-containing powdered charcoal causes a decrease by 10 dB on average of its EMR transmission coefficient in the frequency range 0.7–17.0 GHz.

EMR reflection coefficient values of the considered panels in the frequency range 0.7–2.0 GHz vary from –1.0 to –7.0 dB, and in the frequency range 2.0–17.0 GHz – from –4.0 to –17.0 dB, regardless of the measurement mode of this parameter. A resonant decrease from –4.0 to –17.0 dB of EMR reflection coefficient of the considered panels was recorded in the frequency range 6.0–15.0 GHz.

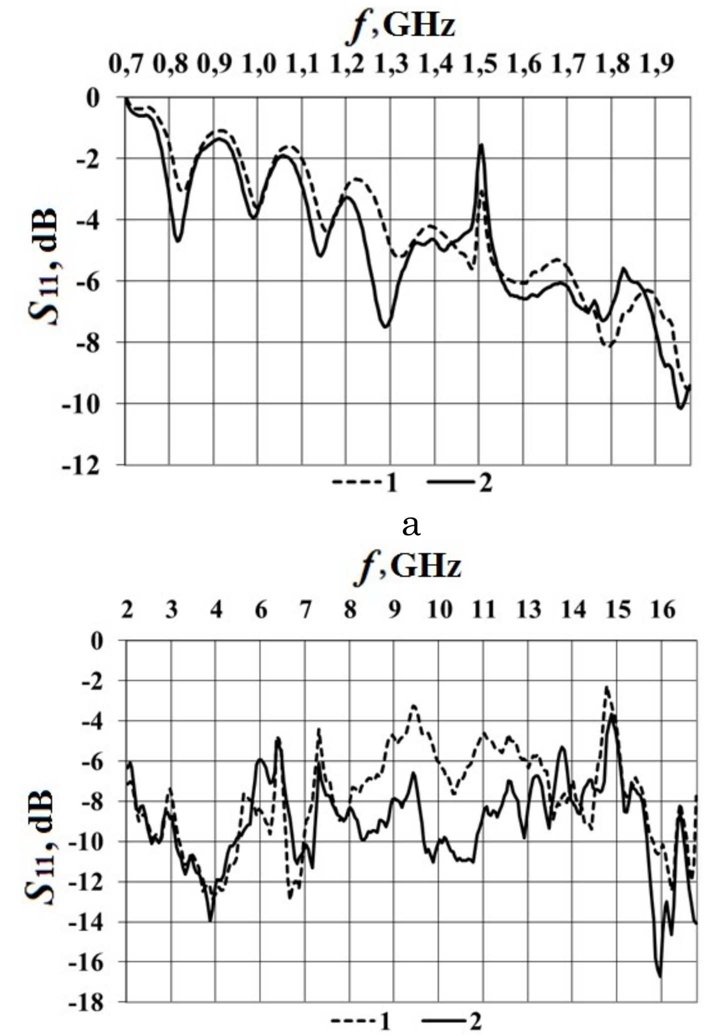
Figures 4.27, 4.28 show the frequency dependences of EMR transmission and reflection coefficients of panel samples made on the basis of the water-containing mixture of powdered charcoal and titanium dioxide.



a

b

Figure 4.27 – Frequency dependences of EMR transmission coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of a panel sample based on the water-containing mixture of powdered charcoal and titanium dioxide



a

b

Figure 4.28 – Frequency dependencies of EMR reflection coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of samples of panels based on powdered charcoal and titanium dioxide: 1 – reflection coefficient, measured in mode 1; 2 – reflection coefficient measured in mode 2

It was established that EMR transmission coefficient values in the frequency range 0.7–17.0 GHz of a panel based on the water-containing mixture of powdered charcoal and titanium dioxide vary from –18.0 to –30.0 dB, and EMR reflection coefficient values measured in mode 1 vary from –1.0 to –16.0 dB. EMR reflection coefficient values of the considered panels, measured in mode 1, in the frequency range 8.0–13.0 GHz, exceed by 1.0–5.0 dB the similar parameter values measured in mode 2. In the frequency ranges 0.7–8.0 GHz and 13.0–17.0 GHz, the indicated values don't differ significantly.

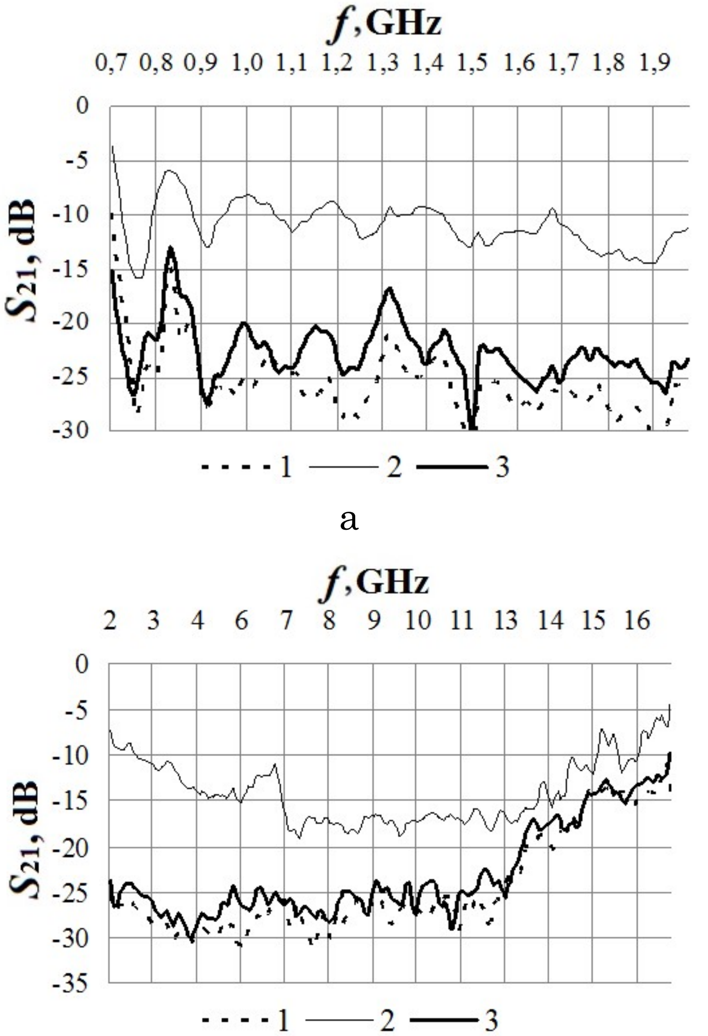
A resonant decrease in EMR reflection coefficient of the considered panels was recorded in the frequency ranges 2.0–6.0 GHz (from –6.0 to –14.0 dB), 15.0–17.0 GHz (from –8.0 to –16.0 dB).

Based on the obtained results, it can be concluded that the use of panels for architectural electromagnetic shielding made in accordance with the proposed methodology is promising. The cost of 1 $m^2$ of panels based on the water-containing powdered charcoal doesn't exceed 10 USD, and 1 $m^2$ of panels based on the water-containing mixture of powdered charcoal and titanium dioxide is 20 USD.

### 4.3.3 Flexible Panels Based on Powdered Coal-Containing and Magnetic Materials for Architectural Electromagnetic Shielding

The methodology for manufacturing of flexible multilayer panels for architectural electromagnetic shielding is proposed, according to which the matching layer (the first relative to EMR source) of these panels is made on the basis of polyurethane foam, the absorbing layer (the second relative to EMR source) is based on a mixture of powdered magnetic and coal-containing powder material impregnated with $CaCl_2$ water solution, reflective layer is based on a polyester carbon-containing fabric. The fixing of the panels layers made in accordance with the proposed method is realized by placing it between of polyethylene terephthalate thermofilm fragments and further connecting these fragments around the perimeter using the sealing method. The wave resistance of the construction of electromagnetic shield, made in accordance with the proposed methodology, is characterized by a gradient change relative to the propagation front of the electromagnetic wave, which creates conditions for its better coordination with the wave resistance of the air (compared with the wave resistance of single-layer structures made on the basis of similar materials).

In accordance with the proposed methodology, three types of panel samples were manufactured. The absorbing layer of samples of type 1 was based on the mixture of powdered titanomagnetite and activated carbon, samples of type 2 – the mixture of powdered titanomagnetite and charcoal, samples of type 3– the mixture of powdered titanomagnetite and coconut coal. Figures 4.29–4.31 show the frequency dependences of EMR transmission and reflection coefficients in the range 0.7–17.0 GHz of the indicated panel samples.



a

b

Figure 4.29 – Frequency dependences of the EMR transmission coefficient in the range of 0.7–2 GHz (a) and 2–17 GHz (b) of the studied panels samples: 1 – sample of type 1; 2 – sample of type 2; 3 – sample of type 3

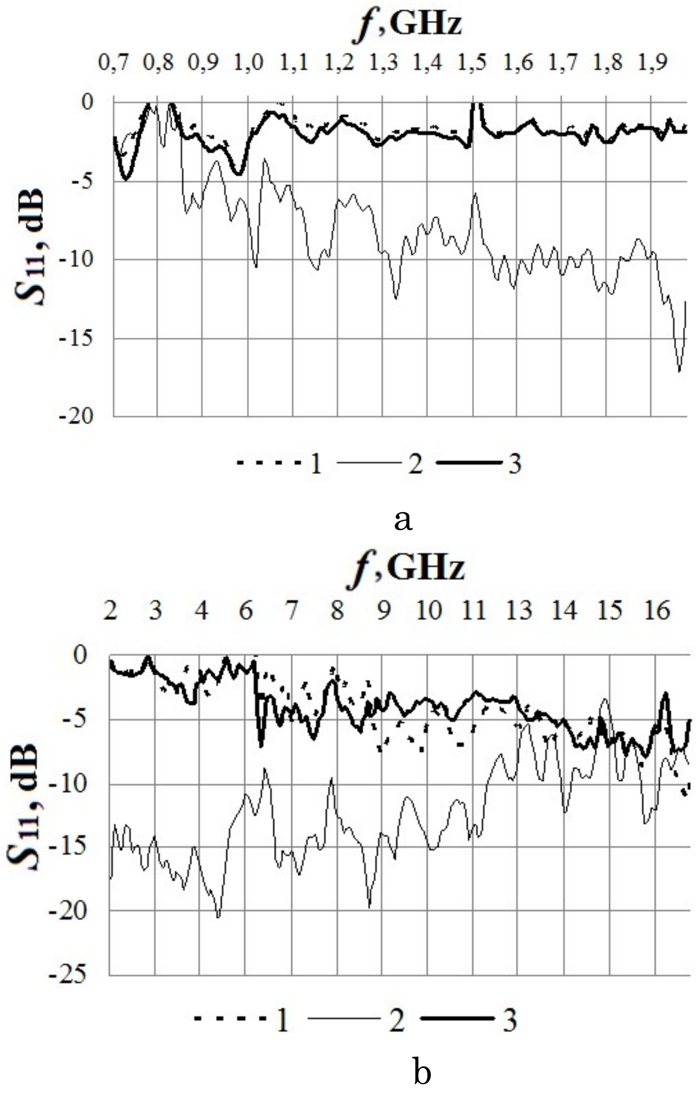
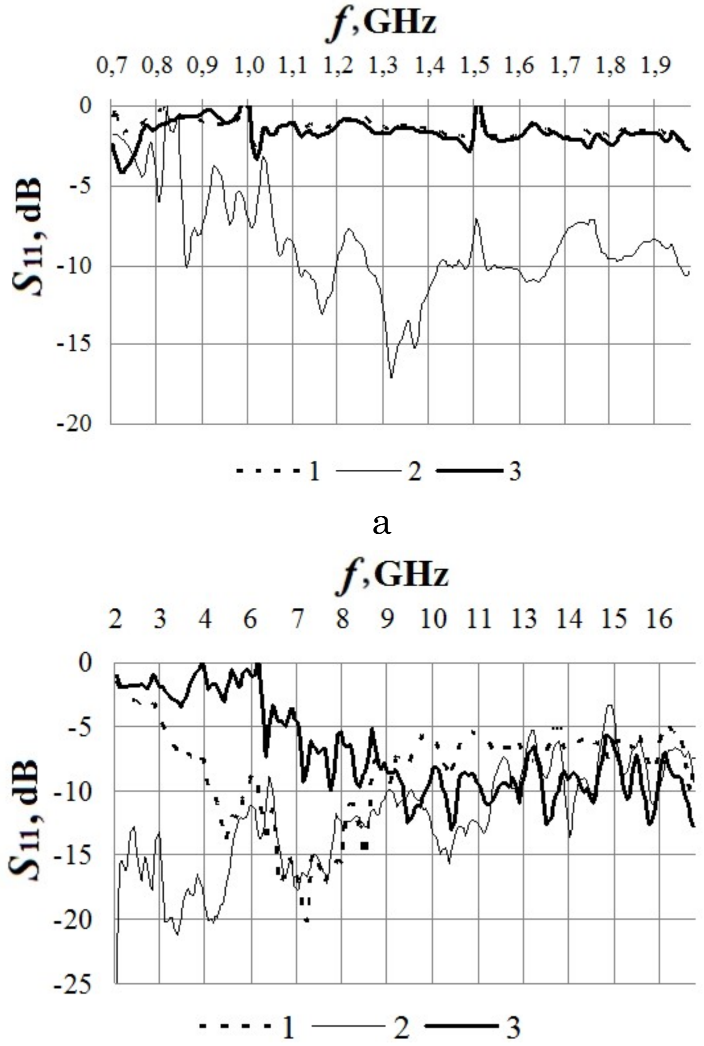


Figure 4.30 – Frequency dependences of the EMR reflection coefficient in the range of 0.7–2 GHz (a) and 2–17 GHz (b) of the studied panels samples obtained as a result of measurements in mode 1: 1 – sample of type 1; 2 – sample of type 2; 3 – sample of type 3



a

b

Figure 4.31 – Frequency dependences of EMR reflection coefficient in the range of 0.7–2.0 GHz (a) and 2.0–17.0 GHz (b) of the studied panels samples obtained as a result of measurements in mode 2: 1 – sample of type 1; 2 – sample of type 2; 3 – sample of type 3

From Figures 4.29 and 4.30 it follows that the limits of change in EMR reflection coefficient values in the frequency range of 0.7–17.0 GHz of panels based on powdered activated and coconut coal are from –0.1 to –7.0 dB, and the transmission coefficient values are from –10.0 to –30.0 dB. For the panel based on powdered charcoal, the limits of these parameters variation are from –0.1 to –20.0 dB and from –5.0 to –17.0 dB. Panels based on powdered charcoal are characterized by lower EMR reflection coefficient values compared to panels based on powdered activated and coconut coal due to the fact that the specific conductivity values of charcoal vary from 0.14 to 0.45 Sm/m and exceed the specific conductivities of activated and coconut carbons, which vary from $4.6 \cdot 10^{-8}$ to $2.9 \cdot 10^{-5}$ Sm/m and from 0.01 to 0.015 Sm/m.

Based on the results of comparing the characteristics shown in Figures 4.30 and 4.31, it necessary to conclude that EMR reflection coefficient values of panels based on powdered activated and coconut coal in the frequency range 0.7–2.0 GHz are independent of the measurement mode. This allows to conclude that most of the electromagnetic waves in this range are reflected by the surfaces of these panels. EMR reflection coefficient values in the frequency range 2.0–17.0 GHz for a panel based on powdered activated carbon, measured in mode 2, are lower on 1.0–15.0 dB compared to the same values measured in mode 1. In addition, the frequency dependence of EMR reflection coefficient in the range 2.0–17.0 GHz of such panel is characterized by a minimum corresponding to a frequency value of 7.0 GHz. It is due to the interference of electromagnetic waves reflected by the surfaces of the second and third layers of the panel, as well as the metal plate used in measurements in mode 2. In the frequency range 2.0–17.0 GHz, EMR reflection coefficient values of the panel based on powdered coconut coal, measured in mode 2, are lower on 1.0–5.0 dB than the corresponding values measured in the mode 1.

EMR reflection coefficient of the panel based on powdered charcoal, measured in mode 2, in the frequency range 0.7–2.0 GHz is lower on 2.0–5.0 dB than the similar values measured in mode 1. In the frequency range 2.0–17.0 GHz, the value of the considered parameter of these panels doesn’t depend on the measurement mode.

Since panels based on the powdered activated and coconut coal are characterized by low values of EMR transmission coefficient in the frequency range 0.7–17.0 GHz, they can be proposed for use in order to protect information from leakage via the channel of secondary electromagnetic radiation.

Panels based on powdered charcoal, characterized by low values of EMR reflection coefficient in the frequency range 0.7–17.0 GHz, measured in mode 2, can be used to reduce the radar visibility of ground objects.

# CONCLUSION

It was shown that the search and study of new powder materials for electromagnetic shields is very promising. For this sphere, high-porous coals, which are characterized by low cost, belong to these. The main types of such coals are charcoal and activated coal.

It was found that EMR transmission coefficient values in the frequency range 0.7–17.0 GHz and EMR reflection coefficient values (when measuring in the short circuit mode) in the frequency range 0.7–6.0 GHz for shields based on powdered coal-containing materials vary from –1.0 up to –6.0 dB. In the frequency range of 6.0–17.0 GHz, EMR reflection coefficient values of these shields are characterized by a resonant decrease (to –12.0 dB).

The possibility of reducing by 2.0–10.0 dB EMR reflection and transmission coefficients values in the frequency range 0.7–17.0 GHz of electromagnetic shields based on powdered coal-containing materials by introducing an water solution of $CaCl_2$ with a concentration of 30 wt. %, which leads to an increase in 102–106 times of their conductivity values.

Methods for the synthesis of metal-carbon composites based on powdered activated coal based on chemical deposition of nickel and copper particles onto the surface of the latter have been developed and tested. Chemical deposition of nickel particles is based on the use of the water solution based on nickel chloride or nickel sulfate, and the deposition of copper particles is based on the use of the water solution based on copper sulfate. Using X-ray diffraction analysis, it was established the possibility to form nickel (up to 0.4 wt.%) and nickel-containing compounds (up to 20,5 wt. %) or copper (up to 1.9 wt. %) and copper-containing compounds (10.8 wt. %) in the composition of powdered activated coal as a result of the deposition of metal particles on its surface in accordance with the developed methods. We experimentally established a decrease from –2.0 to –14.0 dB of EMR reflection coefficient in the frequency range 8.0–12.0 GHz (when measured in the short circuit mode) of powdered activated coal as a result of the deposition of nickel or copper particles on its surface in accordance with the developed methods.

The methods for the design of electromagnetic shields based on coal-containing powder materials have been proposed. In accordance with these methods, low-cost constructions can be obtained that are characterized by operational advantages such as low weight, low flammability, and flexibility. It was determined that the constructions of electromagnetic shields based on powdered charcoal seem promising for use in order to reduce the radar visibility of ground objects, and the constructions based on activated and coconut coal – in order to protect information from leakage via the secondary electromagnetic radiation channel and inductions.

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