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Study of the Protective of Polyethylene Terephthalate Polymer

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Abstract

This paper examines the properties of the synthetic polymer material polyethylene terephthalate to reflect, absorb, and scatter radio waves across various frequency ranges. The use of durable polyethylene terephthalate films to protect objects and personnel from detection by non-ionizing radiation is substantiated. The transmission, reflection, and scattering of radio waves by polyethylene terephthalate films with radio-absorbing fillers is studied. A setup for conducting experimental studies in an echo-absorbing room is developed. It is found that mesh coatings made of interwoven matted polyethylene terephthalate tapes reduce radio wave reflection by more than tenfold compared to smooth film. Polyethylene terephthalate filled with stainless steel microparticles (up to 1% of the polymer volume) exhibits minimal reflectivity. It has been determined that mesh coverings woven from strips of this material no more than 25 microns thick in the frequency range of 1 to 10 GHz attenuate radio wave reflections from the protected object by more than 40 times, or by 16 decibels. Experiments have proven that lightweight, flexible, and tear-resistant coverings made of the polymer polyethylene terephthalate can be successfully used to protect objects and personnel from detection by non-ionizing radiation.

Keywords: polymer material, radio-absorbing, radio waves, reflection coefficient, radioprotective coatings.

INTRODUCTION

Protection of facilities, equipment and personnel from radar detection is an important technical task that requires new solutions. The task of reducing the radar visibility of objects and equipment is usually solved by using special protective coatings. This determines the relevance of searching for new effective protective coatings experimentally and their experimental investigation. Radar-absorbing camouflage coatings are widely used to protect personnel from exposure to high-frequency signals and to shield objects and equipment from radar detection. These coatings are designed to protect people, equipment, and structures from both visual and optical detection by radars of various detection devices.

Currently, a wide range of radioprotective coatings are used for various purposes. Radioprotective coatings have found application in the creation of anechoic chambers used for high-quality measurements and verification of antenna equipment. They are also used for radar protection of facilities, equipment, and personnel. Protective radio-absorbing coatings should attenuate the radar signal reflected from the protected object by tens or hundreds of times. The protection of equipment from visual surveillance and from drone video cameras can be ensured by high-quality selection of the radar-absorbing camouflage coatings color, achieving maximum similarity with the color scheme of the environment of the protected object.

Reducing the radar signature of objects and equipment is difficult for many reasons. The main one is the need to protect against electromagnetic radiation in a very wide range of radio frequencies. For example, radars operate at various frequencies in a wide frequency range from hundreds of megahertz to more than ten gigahertz [1]. Another reason is the excellent ability of most equipment, made mainly of metals, to reflect radio waves, which requires the radar-absorbing camouflage coatings to attenuate electromagnetic radiation in a wide frequency range by tens or hundreds of times, which is possible only with the use of special materials and sophisticated technologies for their production [2, 3].

Currently, a large class of radiation protection coatings is known. They are used to create anechoic rooms and radar protection of facilities, equipment and personnel. The industry produces a wide range of radio-absorbing materials of various types based on the principles of absorption and scattering of radio waves, both on one of these principles and on their combined application. Various materials are used for the manufacture of masking radio-absorbing coatings: ferromagnetic, polymer with powder fillers, ceramic from sintered metal oxides with low ohmic resistance, thin-film nanostructured, etc. [4, 5].

MATERIALS AND METHODS

The classification of radio-absorbing materials is carried out according to various parameters, for example, such as:

- physical principles used,

- the bandwidth of the operating frequencies,

- the type of material used,

- bulky or leafy.

Three physical principles are used to protect against electromagnetic radiation from radar-absorbing camouflage coatings guidance and detection devices:

- absorption and conversion of electromagnetic radiation into heat;

- scattering of electromagnetic radiation over a large area far from the radiation source;

- compensation of external electromagnetic radiation by antiphase radiation.

Methods based on the absorption and scattering of radio waves are more commonly used for equipment protection, since the external field compensation method requires the radar-absorbing camouflage coatings thickness to correspond to a quarter-wavelength of the radiating field. The compensation method actively protects against electromagnetic radiation only at a fixed frequency and is therefore not often used to protect objects and equipment using radar-absorbing camouflage coatings. The compensation method of protection has found primary application in protecting production personnel from unwanted radiation from powerful industrial high-frequency installations operating at fixed frequencies.

Protective coatings are used for various purposes. The intended use of protective coatings can be divided into two classes:

- protection of personnel and equipment from adversely affecting high-frequency signals;

- protection of objects from radar detection.

Depending on the intended use of protective coatings, different requirements are imposed on them. For example, when protecting personnel and sensitive radio equipment from high-frequency radiation, it is necessary to ensure minimal transmission of radio waves through the protective coating. When camouflaging objects, protective coatings must ensure minimal reflection of radio waves, allowing the coating to be radio-transparent

To increase efficiency, stationary objects close the radar-absorbing camouflage coatings s with diffuse reflection of radio waves, in which radio waves are reflected from an object at different angles, scattering in space. To organize the scattering of radio waves, the radar-absorbing camouflage coatings surface must have randomly placed irregularities, with the size of the irregularities commensurate with the wavelength of the incident wave [6].

The radar-absorbing camouflage coatings should be lightweight, flexible, durable, resistant to temperature and climatic changes, and should not take up much space. Such conditions are best met by sheet and film materials with conductive fillers. The main parameters of such radio–absorbing materials that determine the absorption efficiency of radio waves are:

- chemical composition;

– film thickness;

– the concentration of filler from conductive particles [7]. Examples of commercially available radio-absorbing materials are shown in Figure1.

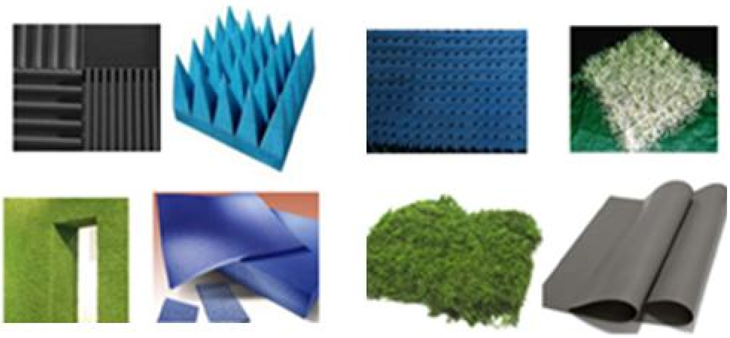

Figure 1. Samples of radio-absorbing materials

To improve efficiency, stationary objects are covered with radar-absorbing camouflage coatings with diffuse radio wave reflection, in which radio waves are reflected from the object at various angles, dispersing into space. To improve efficiency, stationary objects are covered with diffuse reflective reflectors, in which radio waves are reflected from the object at various angles, dispersing in space. The protecting object should not have rectangular corner reflectors, which reflect the incident wave toward the irradiating device. To ensure radio wave dispersion, the radio-absorbing materials surface should have randomly distributed irregularities, as shown in Figure 2a), with dimensions commensurate with the wavelength of the incident wave [8]. When a radio wave falls on a protected object, according to Fresnel's laws, the incident wave ***Einc*** is refracted and divided into reflected ***Eref*** and transmitted ***Etr*** waves, as shown in Figure2b).

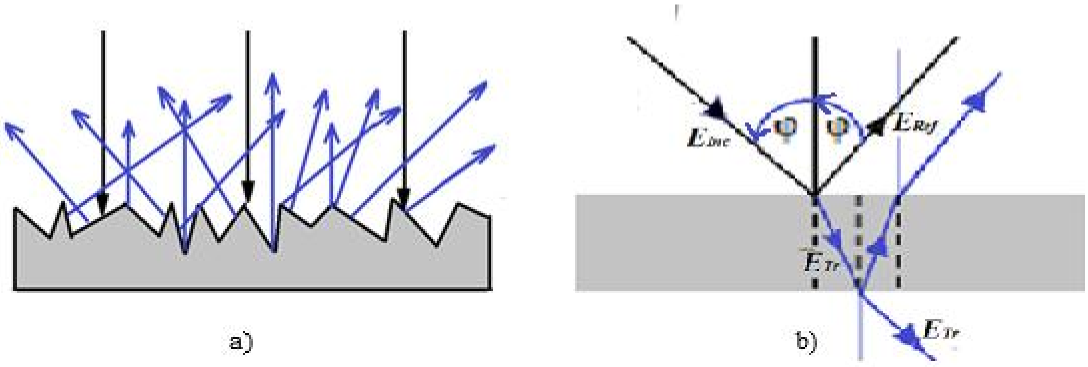

Figure 2. Fall of radio waves on sheet material: a) with diffuse reflection of waves; b) with reflection, refraction and transmission of radio waves on smooth material

By covering a metal object with a protective coating made from a polyethylene terephthalate film with an embedded conductive filler, we force a radio wave to fall from the air into a dielectric medium with a conductive filler, and then to the interface with the metal of the protected object. The electromagnetic wave induces currents in the conductive filler and causes charge movement, which leads to the conversion of the wave energy into thermal energy. Therefore, significantly less electromagnetic radiation energy will reach the protected object and less energy will be reflected from it. When a radio wave falls on a material, in accordance with Fresnel's laws, the incident wave is refracted and divided into reflected and transmitted [8]. The complex reflection coefficient

$$\dot{K}_{ref}=\frac{\dot{E}_{ref}}{\dot{E}_{inc}}$$

depends on the complex refractive index $\dot{n}$ associated with the complex dielectric constant of the material $\dot{\varepsilon}$ by the equation

$\dot{n}=\sqrt{\dot{\varepsilon}}$.

In this case, the imaginary part of the refractive index is related to the absorption of radio waves in the medium, and the real part is related to their reflection. The task of increasing the efficiency of radio-absorbing coatings is to find the material with the best ratio of the real and imaginary parts of the refractive index of radio waves in this material.

Films made of synthetic materials began to be used for the manufacture of flexible and lightweight masking radio-absorbing coatings. In the experiments, we will use a 20 nm thick polyethylene terephthalate film with a conductive filler made of steel stainless nanoparticles. Polyethylene terephthalate films are easy to process, moisture-resistant and can withstand temperatures up to 260 °C [9].

By closing a metal radar-absorbing camouflage coatings object based on a polyethylene terephthalate film with a conductive filler, we have a radio wave falling from the air into the medium of a dielectric with a conductive filler, and then onto the interface with the metal of the protected object. An electromagnetic wave in a conductive filler induces currents and a movement of charges occurs, which leads to the conversion of wave energy into thermal energy. Therefore, significantly less electromagnetic radiation energy will reach the protected object and less energy will be reflected from it.

The distribution of a radio wave into two components - reflected and scattered in a dielectric with a weakly conductive filler depends on the filler material and on a number of random factors, such as the random location of filler microparticles, the uniformity of their concentration, and the shape of the microparticles. This creates a problem in the analytical determination of the reflection coefficient and the level of protection of radar-absorbing camouflage coatings technology, and the problem has to be solved experimentally [10].

Films made of synthetic materials began to be used to manufacture flexible and lightweight radar-absorbing camouflage coatings. The currently accepted paradigm of maximum attenuation of the radar signal to protect one's equipment needs to be adjusted. The desire to maximally attenuate the reflected radar signal leads to the fact that the invisible object is perceived by the locator as a black spot. The absence of reflections at the location of the protected object against the background of reflections from the surrounding environment allows one to determine the coordinates of the object. [11].

Therefore, it is necessary to reduce the reflection of electromagnetic radiation from the protected object to the level of electromagnetic radiation reflection from the surrounding environment. Therefore, the objective of the experimental study is to determine the electromagnetic radiation attenuation coefficient from the use of masking radio-absorbing coatings. This is necessary to select an absorbing material with reflections characteristic of a typical equipment operating environment. Typical types of surfaces surrounding the protected object: coniferous forest, deciduous forest, mixed forest, mountain slopes, asphalt pavement, grassy terrain and other types of underlying surface [12].

RESULTS

Experimental studies will be conducted in an echo-proof room of Vladimir State University named after Alexander Grigorievich and Nikolay Grigorievich Stoletovs. As a protected object, we use a steel sheet painted in a protective color, one square meter in size, located in the far zone from the measuring antennas used, as shown in Figure 3,

Figure 3. Measuring unit in the anechoic room of the Vladimir State University named after A.G. and N.G. Stoletovs

For experimental studies, we will use a mesh woven from matted polyethylene terephthalate film strips with a metal filler as a radar-absorbing masking coating. The uneven surface of the coating will further reduce the reflected energy due to the scattering capacity of uneven matte coatings.

DISCUSSION

For experimental studies, a matted polyethylene terephthalate film with fillers made of microparticles of stainless steel was chosen as a dielectric. We use frosted polyethylene terephthalate films as masking radio-absorbing coatings, which additionally reduces the reflection energy due to the scattering ability of matte coatings.

The energy value of the reflected signal is mainly determined by the properties of the absorber, but it depends not only on its composition and linear ohmic resistance, but also on the thickness of the masking radio-absorbing coatings. Experiments were conducted using 20- micron-thick films and a protective mesh made from this film. The mesh was made from strips of polyethylene terephthalate film with a mesh size of 50x50 mm. Stainless steel nanoparticles, comprising 5% of the volume of the polyethylene terephthalate film, were used as an absorbent filler.

The experimental scheme is shown in Figure 4. An Agilent spectrum analyzer, wide-band antennas, and standard microwave signal generators were used in the experiments.

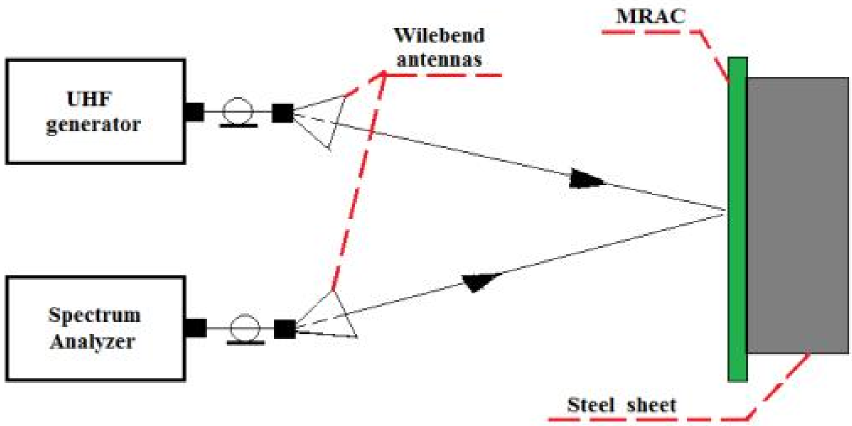

Figure 4. Diagram of the measuring system

The measurements were carried out in the frequency range from 1.0 to 10.0 gigahertz in increments of 2.0 gigahertz. The reflection from the painted steel sheet and from the same, but closed, masking radio-absorbing coat was measured. The difference in these measurements results in a weakening of the electromagnetic radiation from the use of radio-absorbing coat. Due to the loose fit of the radio-absorbing coat to the metal sheet, repeated series of measurements gave results that differed by up to 10% from the first measurements. Therefore, ten series of measurements were performed at each frequency with the network outweighing and the average results were found.

Stainless steel nanoparticles, comprising 5% of the polyethylene terephthalate film's volume, were used as an absorbent filler. The weight of one square meter of this protective coating did not exceed 200 grams. Stainless steel nanoparticles, comprising 5% of the polyethylene terephthalate film's volume, were used as an absorbent filler. The weight of one square meter of this protective coating did not exceed 200 grams.

Figure 5 shows the experimentally obtained results on determining the reflection coefficient from an object made of steel enclosed by an radar-absorbing camouflage coatings from a network woven with 40 mm wide tapes of films 20 nm thick with a filler of stainless steel nanoparticles.

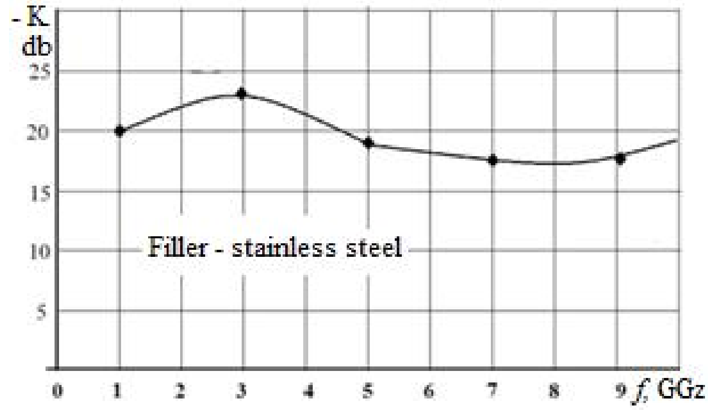

Figure 5. Attenuation of the microwave grid with 40x40 mm grid cells

Measurements were conducted at a room temperature of 20°C. Broadband antennas with linear amplitude-frequency characteristics were used, and the noise level inside the open anechoic room did not exceed –65 dB.

CONCLUSION

Analysis of the obtained results allows us to draw the following conclusions:

1. The results of experimental studies of masking radio- absorbing coat made on the basis of microwave-absorbing light and flexible matted films of polyethylene terephthalate with a thickness of 20 nm with microparticles of conductive materials have been obtained.

2. It is shown that in the frequency range from 1.0 to 10.0 GHz, when creating protective surfaces from a film scattering microwave signals (volumetric weaving), the attenuation of the reflected signal exceeds 16 db.

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