conducted before. Studies conducted around the world are mainly focused on determination of optical and radiophysical characteristics of new materials or new coatings without specific area of application. Some researchers determine optical properties of silver nanoparticles added to polyvinyl alcohol and some researchers are focused on optical properties of various nanostructural films.[11-12] Also some articles are known where optical properties are determined for material obtained by laser decomposition at high temperatures around 700℃.[13] Studies of optical properties of carbon nanotubes added to thermal systems are also conducted.[14]

## CONCEPT HEADINGS

Therefore, the aim of this article is to determine rationality of presented products for space technology as parts of large-sized reconfigurable reflector. Laboratory studies of optical and radiophysical properties of new materials for application in large-sized reconfigurable spacecraft antenna reflectors were carried out on the next structure elements of reflector: load-bearing rod elements, metal tips, polymer ropes and metal aerial curtains. All test objects were conditioned immediately prior to testing not less than 88 hours in standard atmosphere 23/50 (temperature, ℃/relative humidity, %) according to GOST 12423-2013. Tests were also conducted under the same atmospheric conditions. Parameters for standard atmosphere 23/50 are presented in Table 1. Control of atmosphere parameters was performed by relevant measuring instruments.[16]

**Table 1**. Parameters of standard atmosphere 23/50

| Physical quantity, dimension | Value |
|---|---|
| Ambient temperature, °C | 86-106 |
| Relative humidity, % | 45-55 |
| Atmospheric pressure, kPa | 86-106 |

### 1. Laboratory studies of optical properties of materials of load-bearing rod elements

Laboratorystudieswerecarriedoutwith3 kinds of samples of composite materials of load-bearing rod elements: epoxy plastic filled by carbon fibersM46J, M55JandKulon.Optical properties of carbon fiber composites were studied in accordance with developed methodology. The samples had a form of plates with length of 20 mm and width of 20 mm. Three samples were made of each carbon fiber composite. Thus, the total number of samples was 9.Reflection coefficients were determined by spectroscopy method in near infrared range using Nicolet iS50 FT-IR spectrophotometer. Processing of obtained data was carried out on PC using specialized software package OMNIC 9.

### 2. Laboratory studies of optical properties of metal tip materials

Laboratory studies were carried out with 2 kinds of samples of metal tip materials: aluminum alloy AMg-6 GOST 4784-97 andinvaralloy36NGOST 10994-74.Optical properties of metal tips were studied in accordance with developed methodology. The samples had a form of plates with length of 20 mm and width of 20 mm. Three samples were made of each kind of metal tip. Thus, the total number of samples was 6. Reflection coefficients were determined by spectroscopy method in near infrared range using Nicolet iS50 FT-IR spectrophotometer. Processing of obtained data was carried out on PC using specialized software package OMNIC 9.

### 3. Laboratory studies of optical properties of polymer ropes

Laboratory experimental studies were carried out with ropes made of “Armalon” aramid fibers (Table 2).

**Table 2.**Characteristics of analyzed ropes made of aramid fibers

| Brand | Color | Linear density, Tex | Breaking force, N | Modulus of elasticity, hPa | Twist, tpm |
|---|---|---|---|---|---|
| Armalon A | Light-yellow | 56.4 | 19.6 | 100.0 | 120 |
| Armalonx-10 | Brown | 61.7 | 69.7 | 159.8 | 80 |
| ArmalonX-10 | Brown | 63.0 | 105.0 | 125.8 | 0 |

Aramid ropes were wound on a cardboard plate. Flat piece formed by this way had dimensions of 20×20 mm. Reflection coefficients were determined by spectroscopy method in near infrared range using Nicolet iS50 FT-IR spectrophotometer. Processing of obtained data was carried out on PC using specialized software package OMNIC 9.

### 4. Laboratory studies of optical properties of metal aerial curtains of radio engineering application

Laboratory studies were carried out with samples of 6 kinds of metal aerial curtains of radio engineering application: tungsten wire with a diameter of 15 µm, gold plated tungsten wire with a diameter of 15 µm, molybdenum wire with diameter of 20 µm and steel wire with a diameter of 50 µm without coating, with copper coating and nickel coating (Table 3). The samples had different types of weaving and cell sizes.

**Table 3.**Characteristics of investigated metal aerial curtains

| Fiber material | Coating | Fiber diameter, µm | Cell size, mm |
|---|---|---|---|
| Tungsten | - | 15 | 0.2-0.8 |
| Tungsten | Gold | 15 | 0.2-0.8 |
| Molybdenum | - | 20 | 0.2-0.8 |
| SteelEI-708A | - | 50 | 2.5×2.5 |
| SteelEI-708A | Copper | 50 | 2.5×2.5 |
| SteelEI-708A | Nickel | 50 | 2.5×2.5 |

Optical properties of aerial curtains of radio engineering application were studied in accordance with developed methodology. Aerial curtains were mounted on cardboard plate with holes sized 20×20 mm. Three samples were made of each kind of aerial curtain. Reflection and transmission coefficients were determined by spectroscopy method in near infrared range using Nicolet iS50 FT-IR spectrophotometer. Processing of obtained data was carried out on PC using specialized software package OMNIC 9.

**5. Laboratory studies of radiophysical properties of materials of load-bearing rod elements**

Radiophysical properties of load-bearing rod elements were determined in accordance with methodology developed in section 3. Measurements were conducted on samples made of carbon fiber composite of size 200×200 mm. Three identical samples were made. Smoothed coefficient of transmission between antennas in case of radiation into empty space in presence of dielectric substrate is shown in Figure 17. Smoothing of obtained experimental data was applied for results of measurements of transmission coefficients between the antennas in presence of metal plate and plate made of carbon fiber presented in Figure 18.

As it follows from results of measurements in frequency range from 2 to 20 GHz, reflectivity of carbon fiber is equivalent to metal surface. At frequencies from 20 to 43.5 GHz, reduction of level of reflected power is registered in 2-3 dB, which corresponds to losses from 37% to 50%. Since the main load-bearing elements of reflector are placed behind metal aerial curtain forming aerial reflecting surface, their influence on angular pattern is negligible. Consideration of radiophysical characteristics may be necessary in case of radiator struts placement above concave surface of reflector.

**6. Laboratory studies of radiophysical properties of metal aerial curtains of radio engineering application**

Radiophysical properties of metal aerial curtains of radio engineering application were determined in accordance with methodology developed in section 6. Measurements were carried out on samples of steel wire without coating, with copper coating 1 μm thick and nickel coating 1 μm thick. From each kind of aerial curtain 3 samples were made.

## RESULTS

Results of studies are presented in Tables 4-6 in form of dependencies of all spectral optical characteristics on wavelength in infrared and optical spectra (from 0.4 to 2.5 μm) at normal beam incidence.

**Table 4**. Spectral optical properties of carbon composite on the basis of M46J fiber

| Λ, μm | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.2 | 2.4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_\upsilon$ | 0.23 | 0.21 | 0.22 | 0.18 | 0.17 | 0.18 | 0.23 | 0.22 | 0.18 | 0.15 | 0.14 |
| $A_\upsilon$ | 0.77 | 0.79 | 0.78 | 0.82 | 0.83 | 0.82 | 0.77 | 0.78 | 0.82 | 0.85 | 0.86 |

**Table 5**. Spectral optical properties of carbon composite on the basis of M55J fiber

| Λ, μm | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.2 | 2.4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_\upsilon$ | 0.33 | 0.30 | 0.28 | 0.32 | 0.31 | 0.26 | 0.25 | 0.22 | 0.23 | 0.20 | 0.18 |
| $A_\upsilon$ | 0.67 | 0.70 | 0.72 | 0.68 | 0.69 | 0.74 | 0.75 | 0.78 | 0.77 | 0.80 | 0.82 |

**Table 6**. Spectral optical properties of carbon composite on the basis of Kulon fiber

| Λ, μm | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.2 | 2.4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_\upsilon$ | 0.21 | 0.37 | 0.31 | 0.30 | 0.27 | 0.25 | 0.26 | 0.30 | 0.25 | 0.19 | 0.18 |
| $A_\upsilon$ | 0.79 | 0.67 | 0.69 | 0.70 | 0.73 | 0.75 | 0.74 | 0.70 | 0.75 | 0.81 | 0.82 |

Results of studies are presented in Tables 7-8 in form of dependencies of all spectral optical characteristics on wavelength in infrared and optical spectra (from 0.4 to 2.5 μm) at normal beam incidence.

**Table 7**. Spectral optical properties of aluminum-magnesium alloy AMg-6 GOST 4784-97

| Λ, μm | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.2 | 2.4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_\upsilon$ | 0.91 | 0.90 | 0.90 | 0.89 | 0.87 | 0.87 | 0.86 | 0.87 | 0.89 | 0.93 | 0.92 |
| $A_\upsilon$ | 0.09 | 0.10 | 0.10 | 0.11 | 0.13 | 0.13 | 0.74 | 0.13 | 0.11 | 0.07 | 0.08 |

**Table 8**. Spectral optical properties ofinvaralloy 36NGOST 10994-74

| Λ.μm | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 | 2.0 | 2.2 | 2.4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_υ$ | 0.51 | 0.56 | 0.62 | 0.69 | 0.73 | 0.75 | 0.76 | 0.78 | 0.80 | 0.82 | 0.83 |
| $A_υ$ | 0.49 | 0.44 | 0.38 | 0.31 | 0.37 | 0.25 | 0.24 | 0.22 | 0.20 | 0.18 | 0.17 |

Results of studies are shown in Figures1-3 in form of dependencies of all spectral optical characteristics on wavelength in infrared and optical spectra (from 0.4 to 2.5 μm) at normal beam incidence.

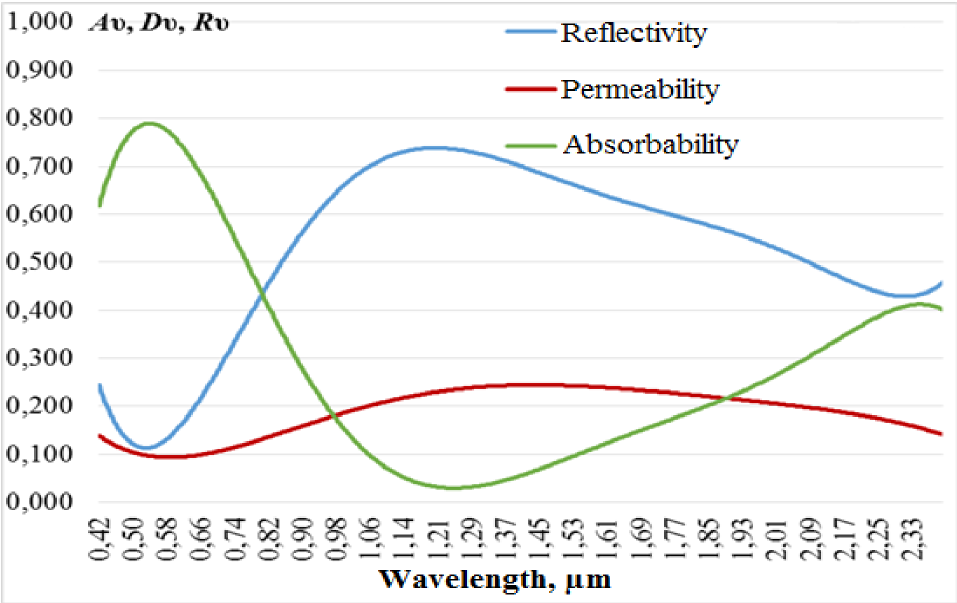



**Figure 1**. Spectral optical characteristics of Armalon yarn x-10 in the range from 0.4 to 2.5 μm

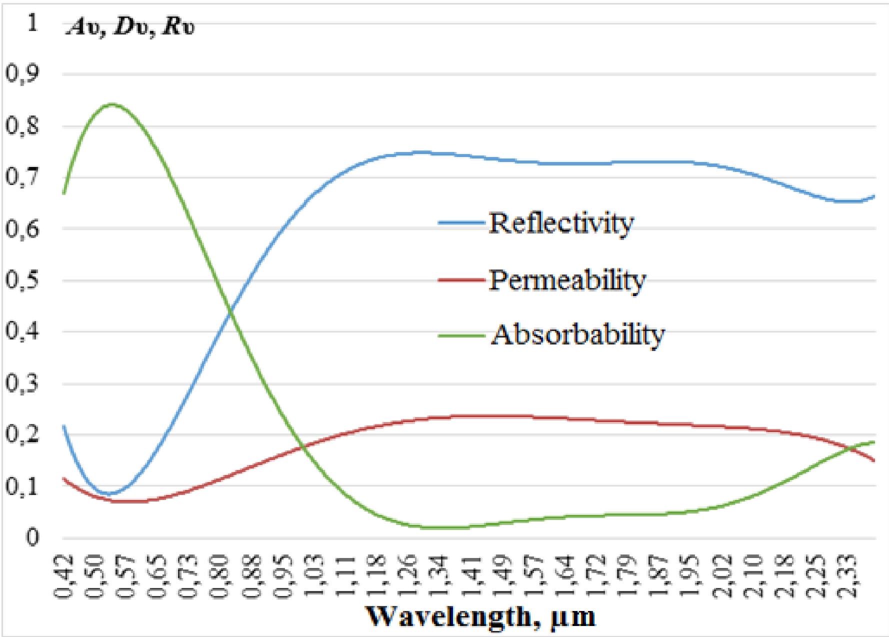



**Figure 2**. Spectral optical characteristics of Armalon yarn X-10 in the range from 0.4 to 2.5 μm

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 8 (2017) pp. 1536-1550

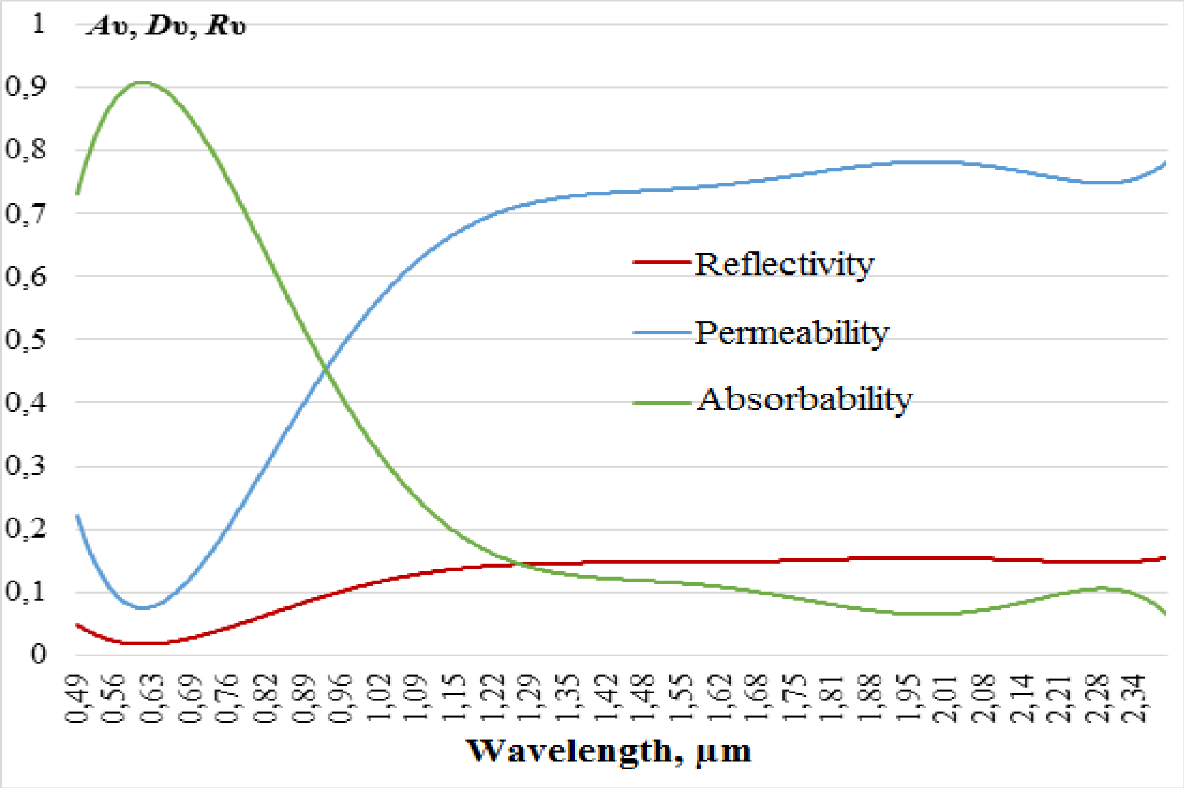




**Figure 3**. Spectral optical characteristics of Armalon yarn-A in the range from 0.4 to 2.5 µm

Results of studies are shown in Figures 4-15 in form of dependencies of all spectral optical characteristics on wavelength in infrared and optical spectra (from 0.4 to 2.5 µm) at normal beam incidence.

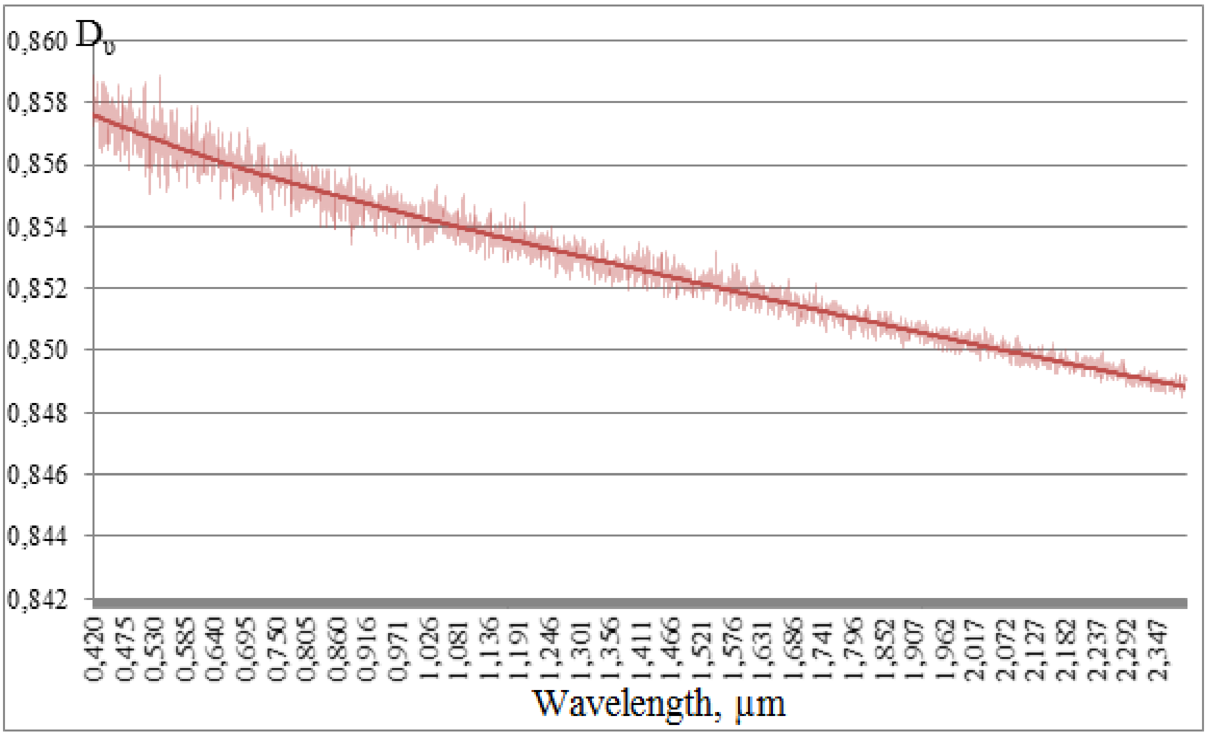



**Figure 4**. Permeability of gold plated tungsten aerial curtain in the range from 0.4 to 2.5 µm

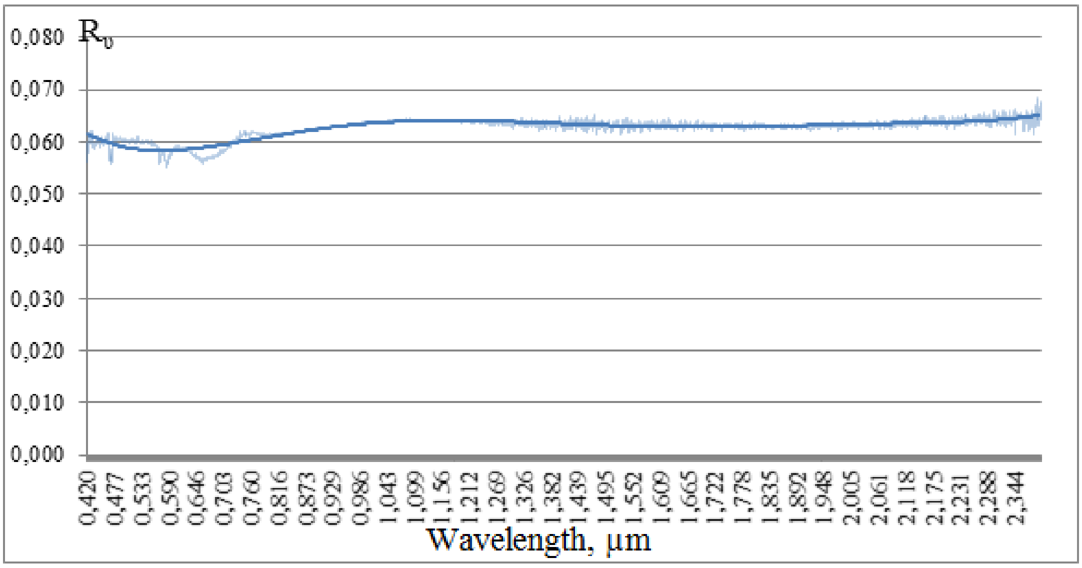



**Figure 5**. Reflectivity of gold plated tungsten aerial curtain in the range from 0.4 to 2.5 µm

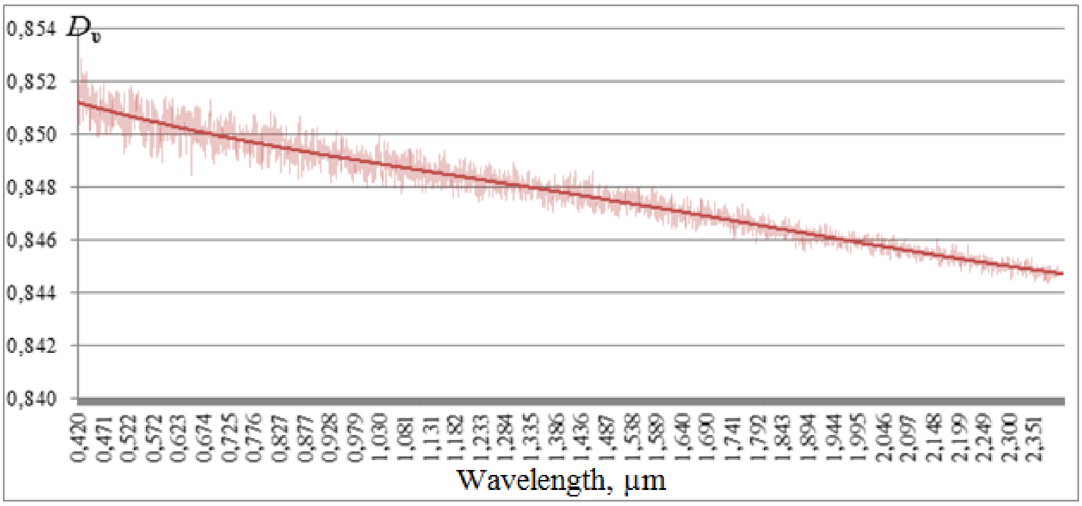



**Figure 6**. Spectral optical characteristics of gold plated tungsten aerial curtain in the range from 0.4 to 2.5 µm

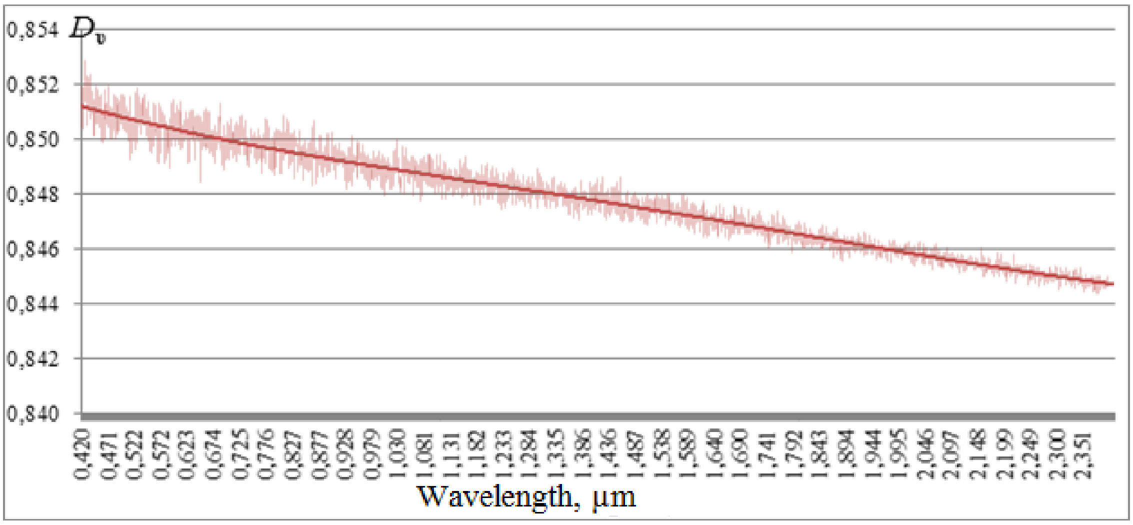



**Figure 7**. Permeability of tungsten aerial curtain in the range from 0.4 to 2.5 µm

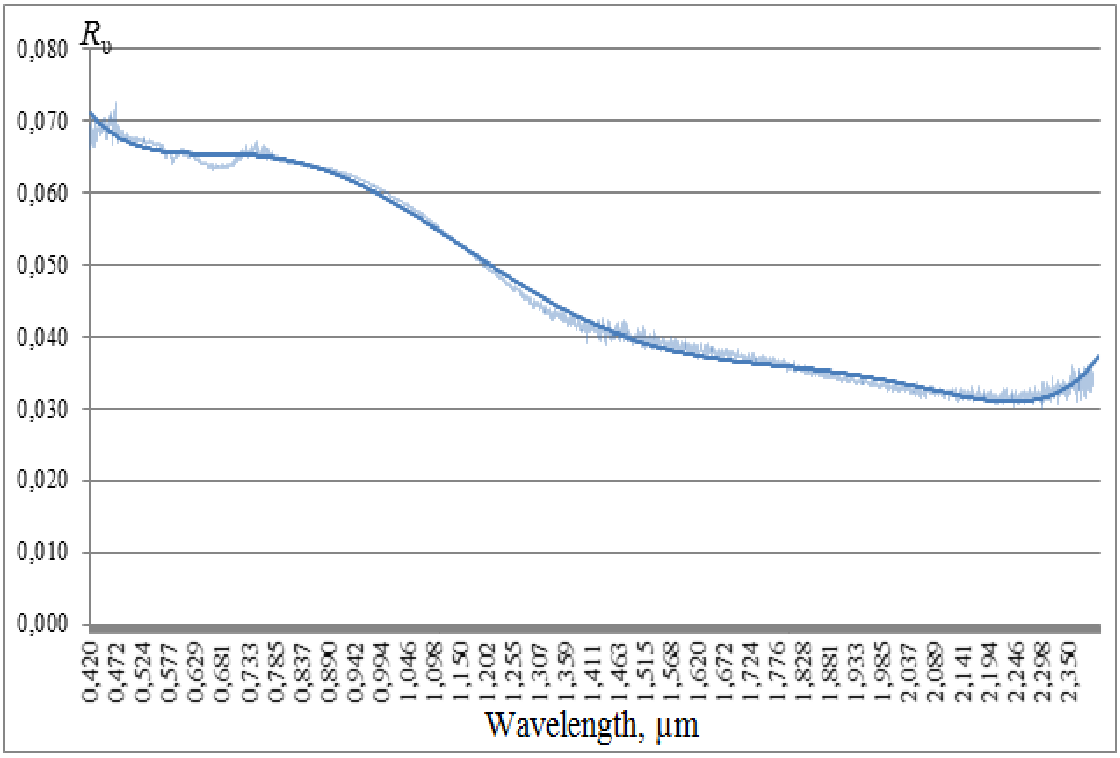



**Figure 8**. Reflectivity of tungsten aerial curtain in the range from 0.4 to 2.5 µm

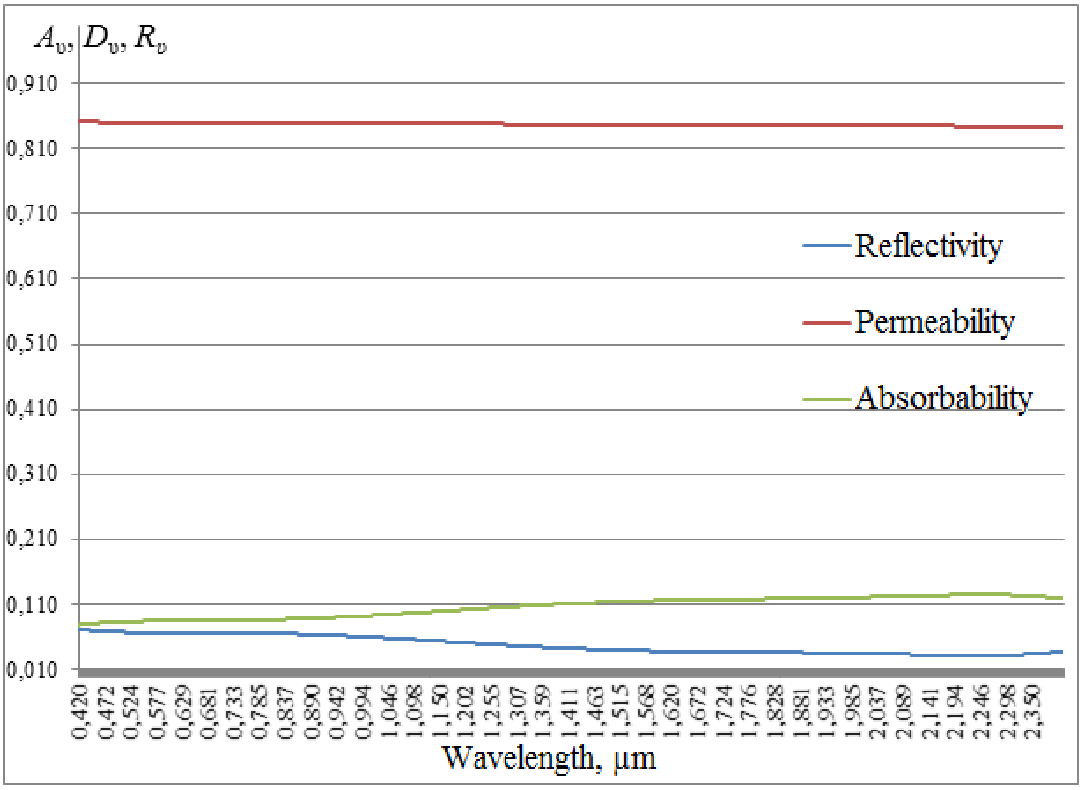



**Figure 9**. Spectral optical characteristics of tungsten aerial curtain

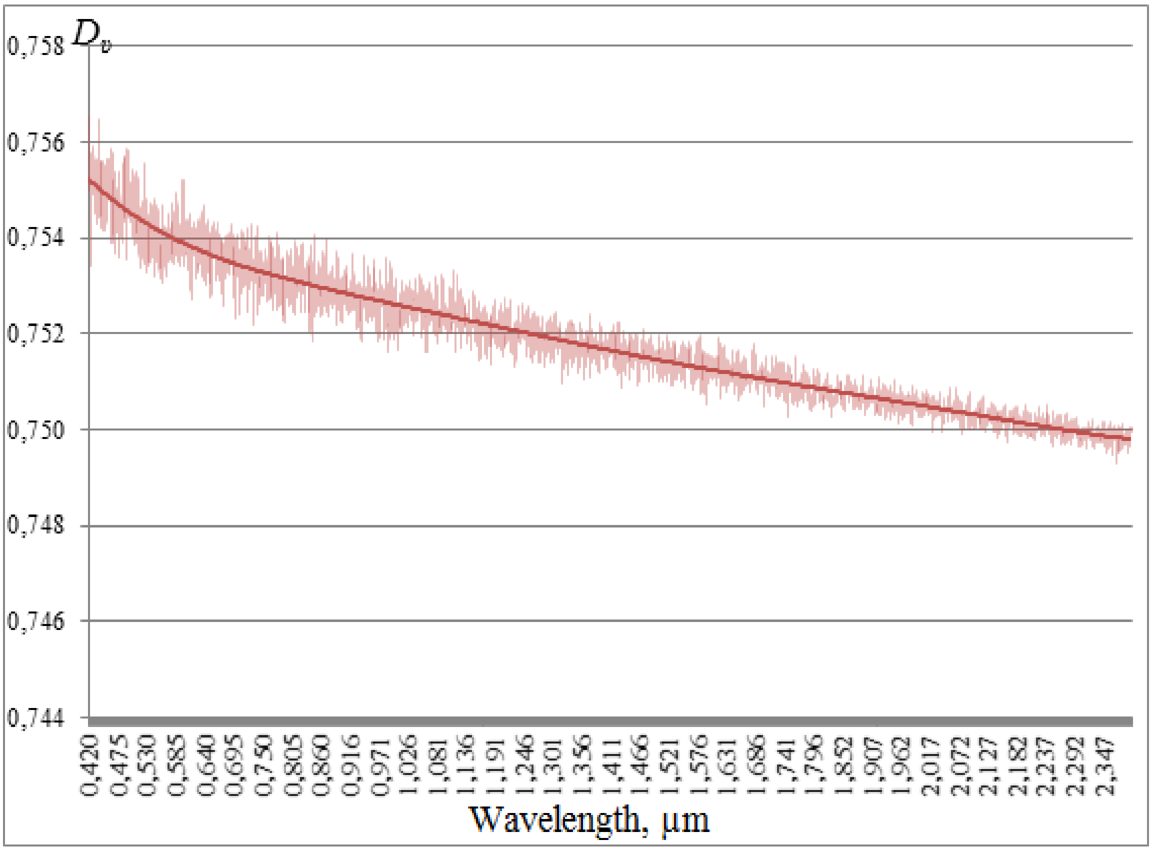



**Figure 10**. Permeability of steel aerial curtain in the range from 0.4 to 2.5 µm

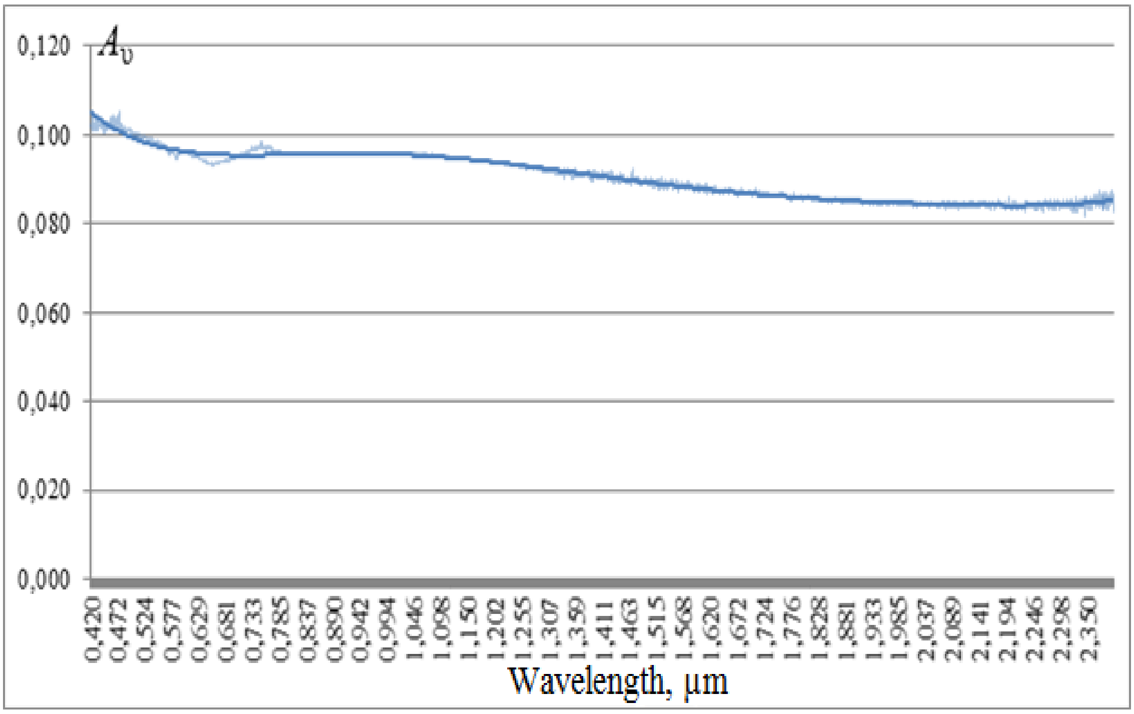



**Figure 11**. Reflectivity of steel aerial curtain in the range from 0.4 to 2.5 µm

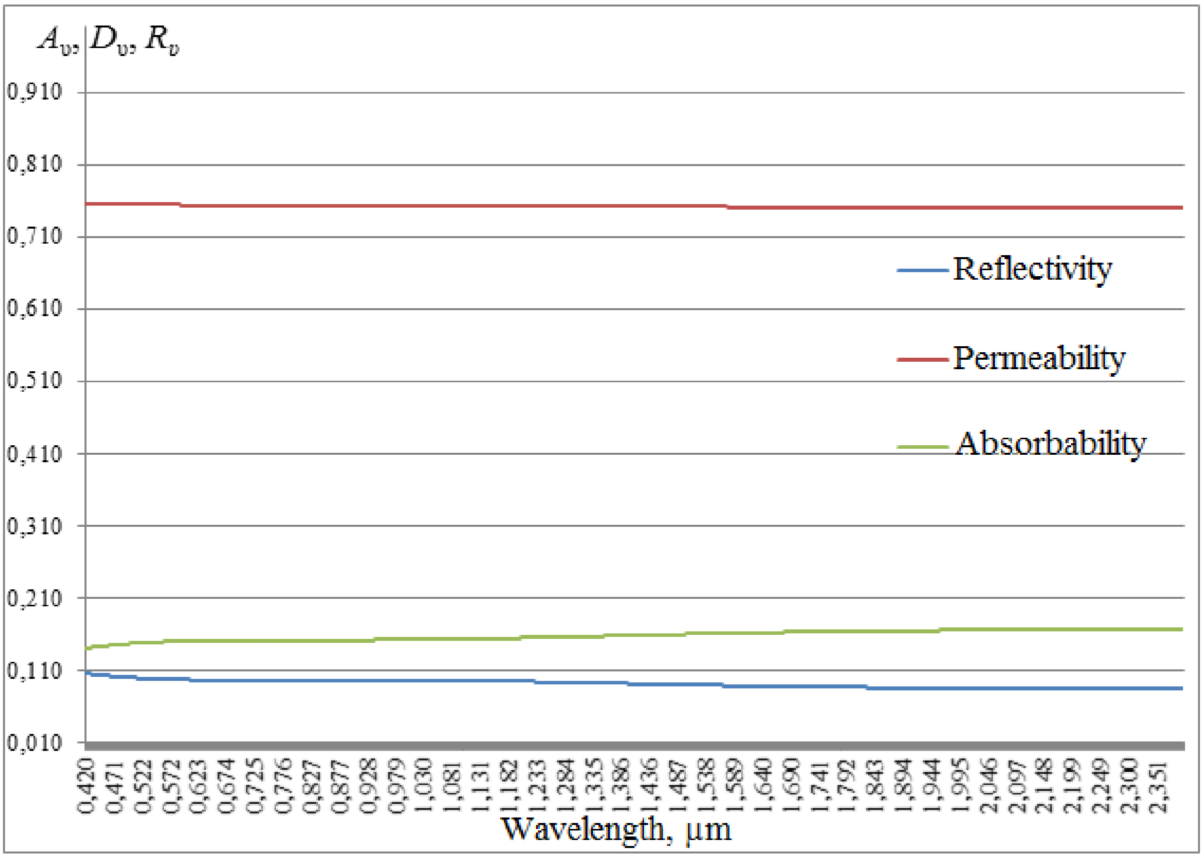



**Figure 12**. Spectral optical characteristics of steel aerial curtain

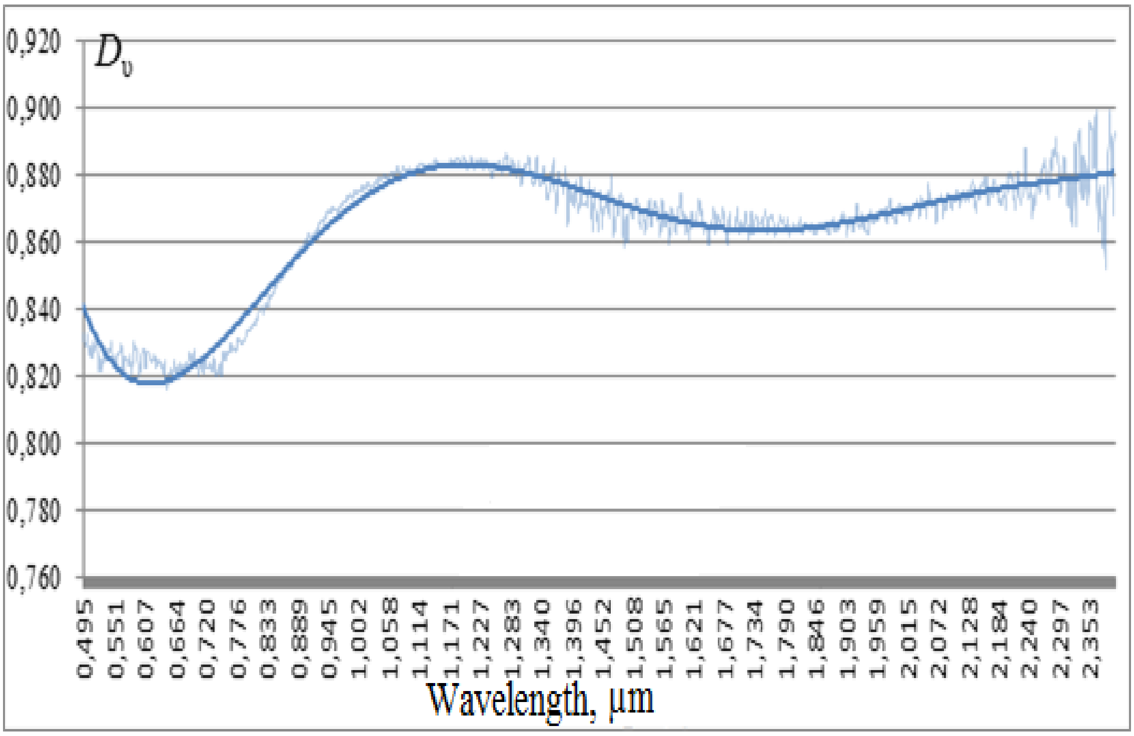



**Figure 13**. Permeability of molybdenum aerial curtain in the range from 0.4 to 2.5 µm

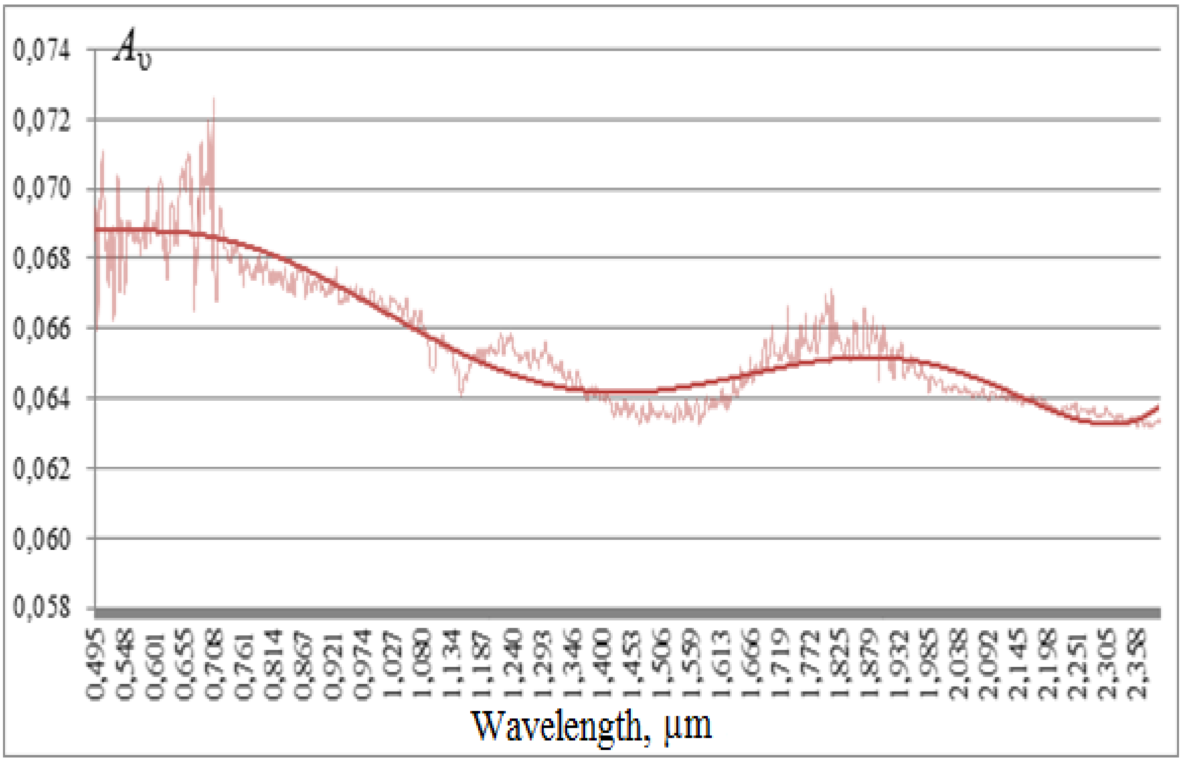



**Figure 14**. Reflectivity of molybdenum aerial curtain in the range from 0.4 to 2.5 µm

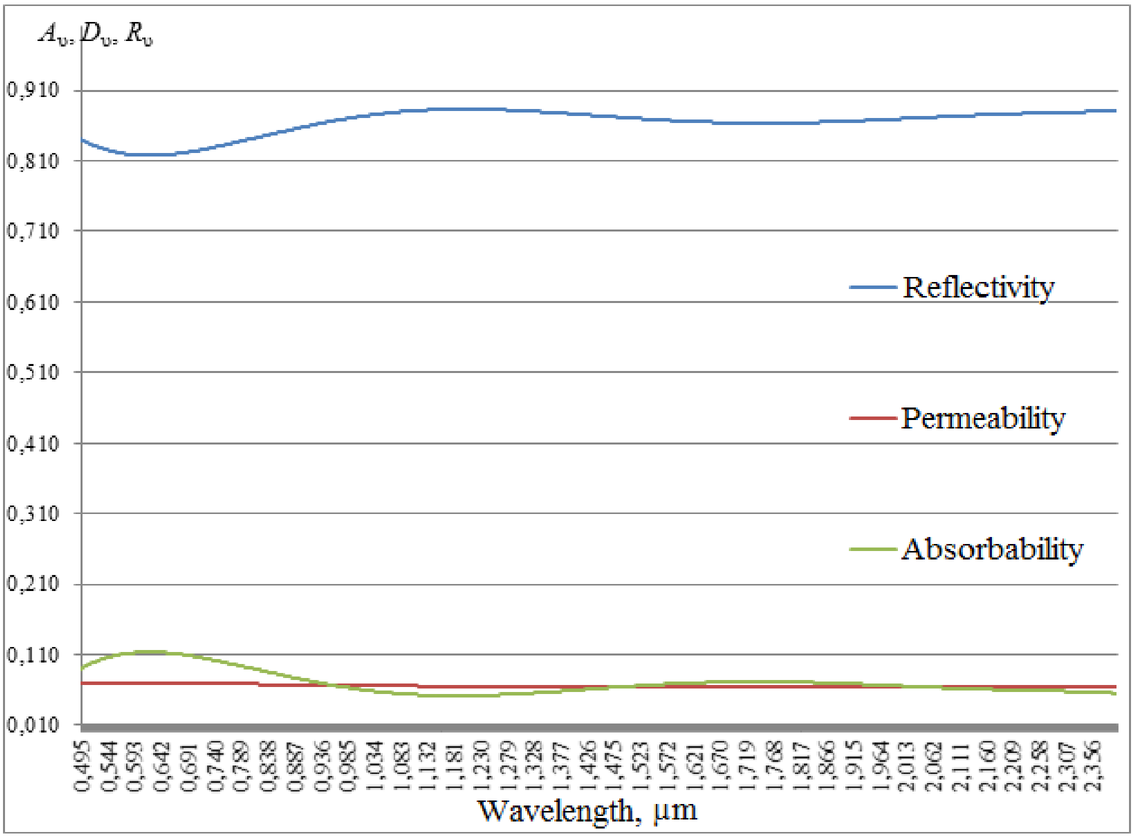
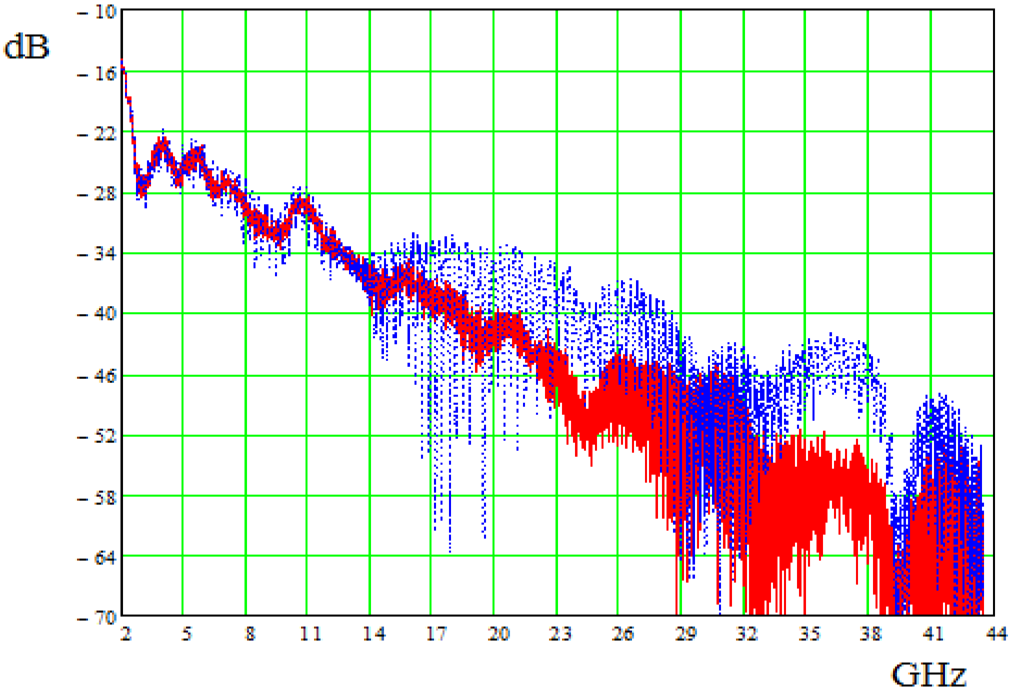
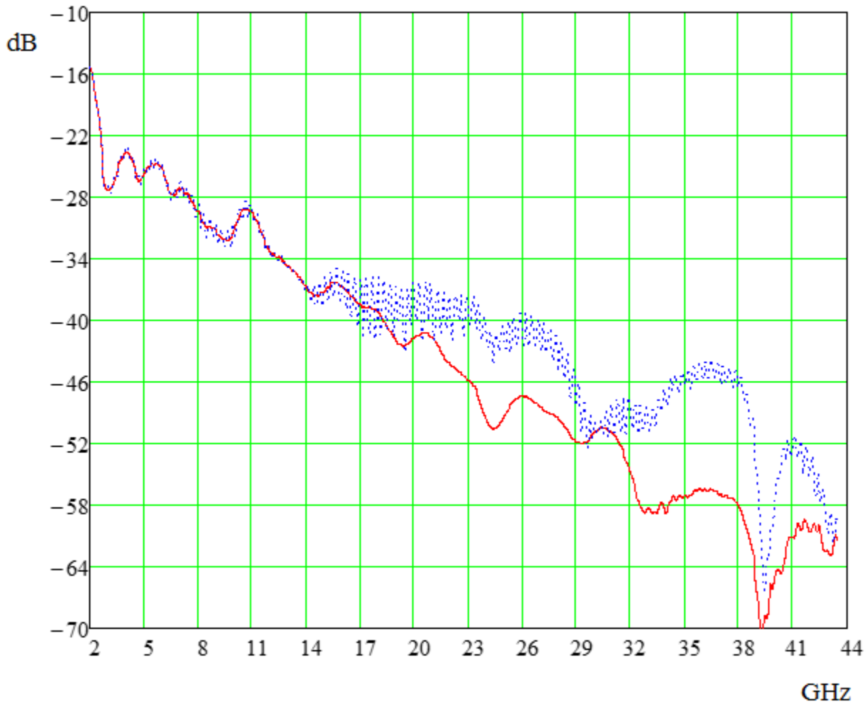



**Figure 15**. Spectral optical characteristics of molybdenum aerial curtain

Results of studies are shown in Figures 16-18 as aerial curtain reflectivity-frequency ratio.

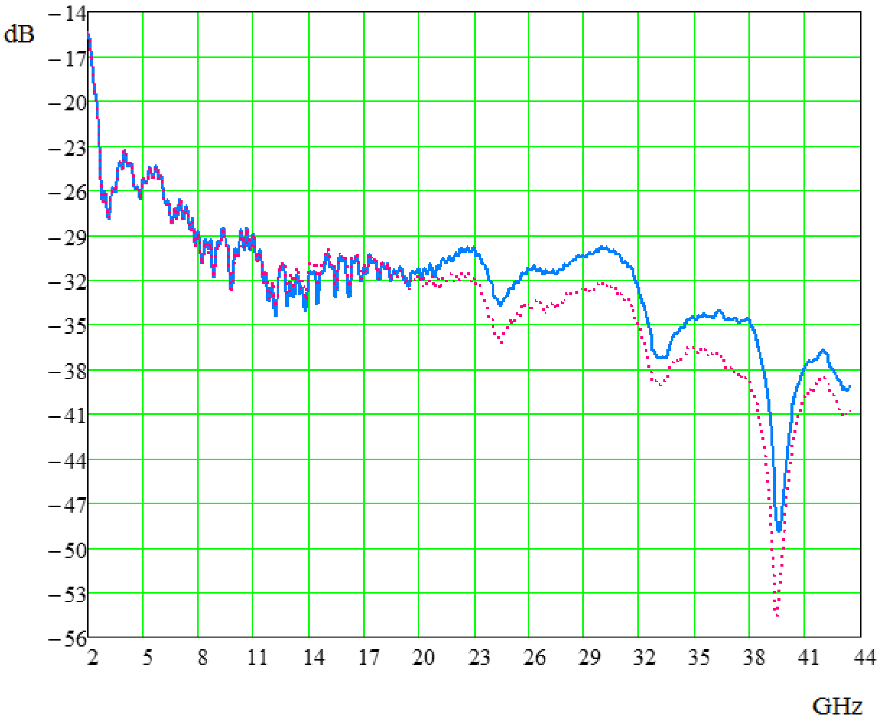



**-** during work into empty space – red full line;
-in presence of polypropylene substrate – blue dotted line
**Figure 16**. Transmission coefficient between antennas




- in presence of substrate and metal plate (red full line);
- in presence of substrate and carbon plastic plate (blue dotted line)
**Figure 17**. Smoothed transmission coefficient between antennas

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 8 (2017) pp. 1536-1550


- in presence of substrate and metal plate (blue full line);

- in presence of substrate and carbon plastic plate (red dotted line)

**Figure 18**. Transmission coefficient between antennas

Results of studies are shown in Figures 19-21 as dependence of aerial curtain reflectivity reflectivity-frequency ratio. Characteristic of wave impedances of aerial curtains of radio engineering application are given in Tables 9-11.

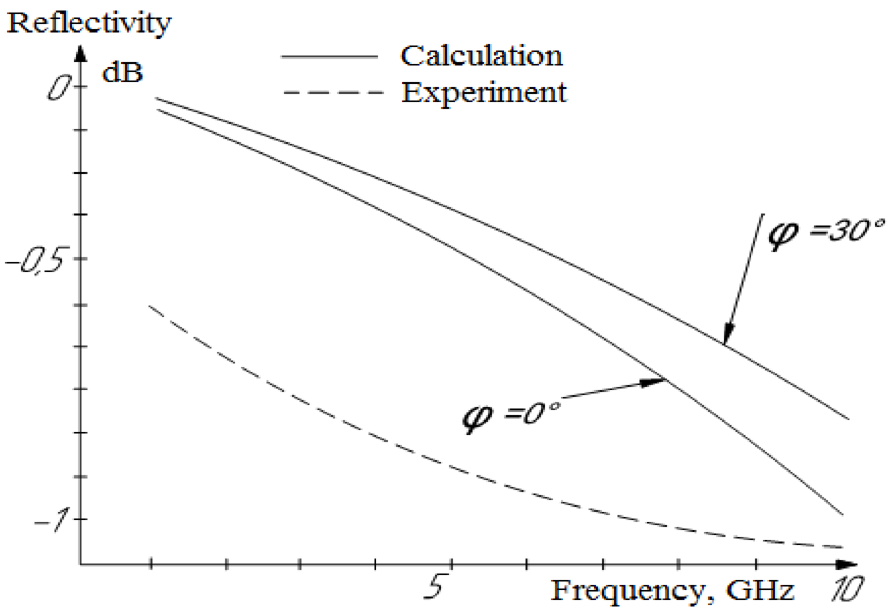



**Figure 19**. Reflectivity of aerial curtain made of uncoated wire EI708A

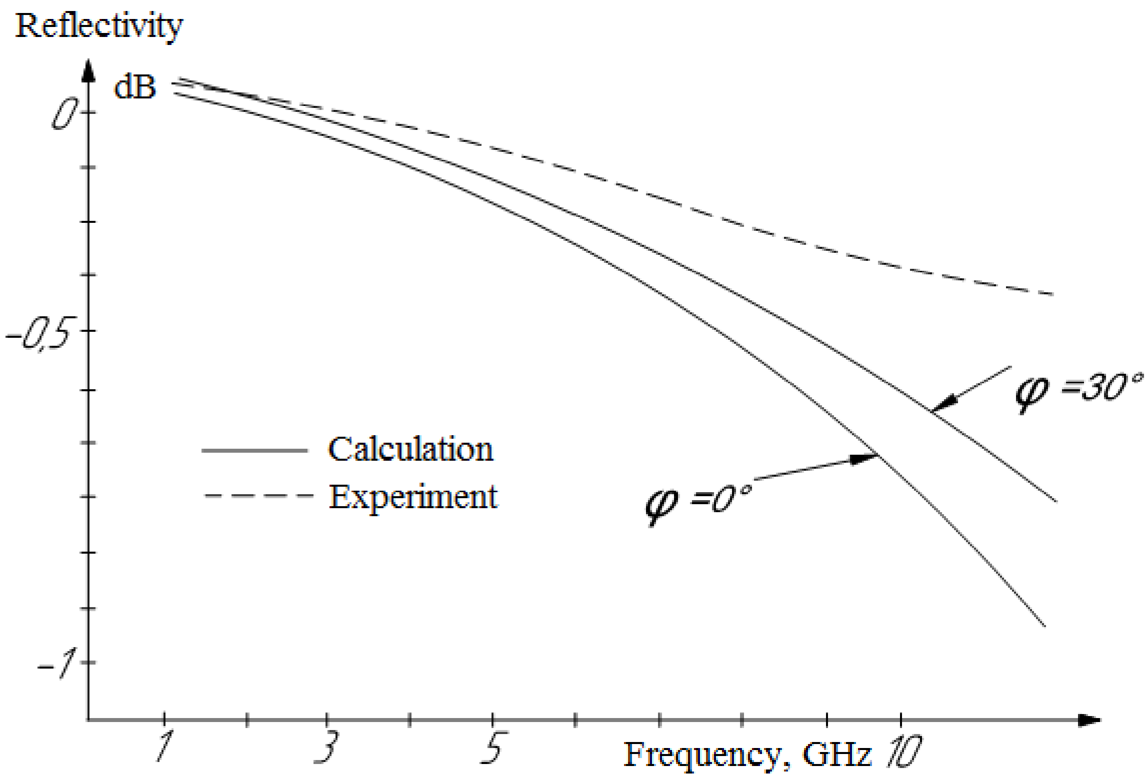



**Figure 20**. Reflectivity of aerial curtain made of copper-coated wire EI708A

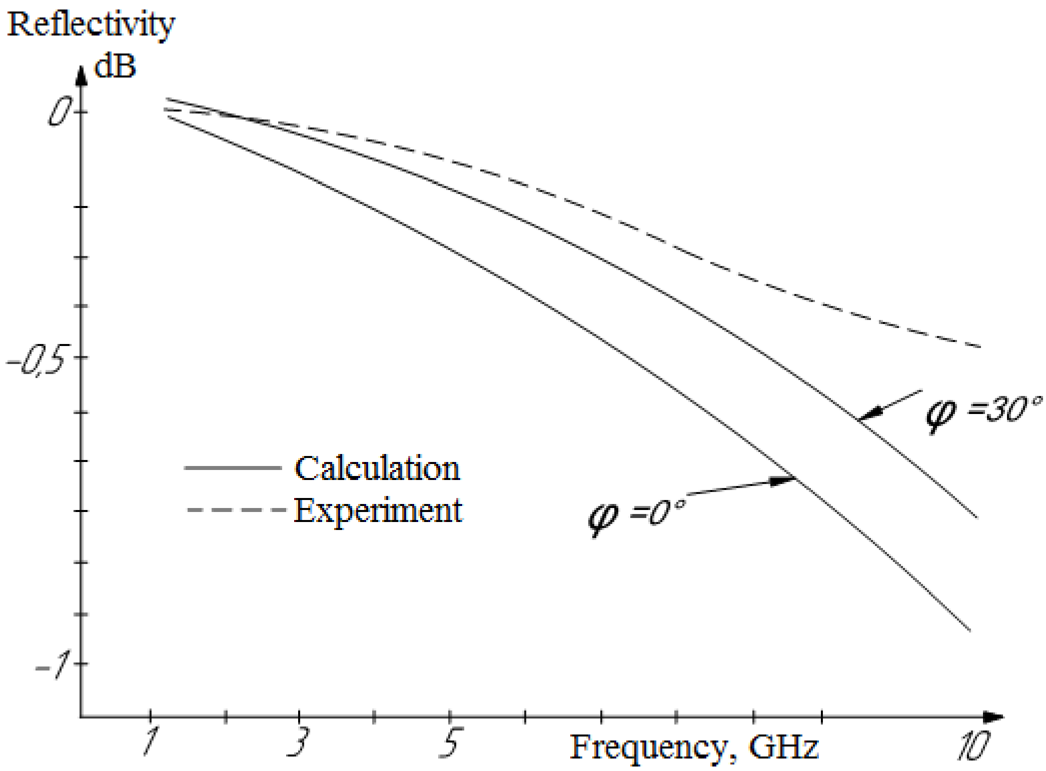



**Figure 21**. Reflectivity of aerial curtain made of nickel-coated wire EI708A

**Table 9.** Characteristic wave impedances of aerial curtain made of uncoated wire EI708A with a cell of 2.5×2.5 mm at frequency *f* =3 GHz

| | Calculation | Experiment |
|---|---|---|
| $\frac{R_c}{\rho_o}\cdot 10^2$ | 0.5 | 6.1 |
| $\frac{X_c}{\rho_o}\cdot 10^2$ | 7.4 | 7.3 |

**Table10.**Characteristic wave impedances of aerial curtain made of uncoated wire EI708A with copper coating at frequency f =3 GHz

| | Calculation | Experiment |
|---|---|---|
| $7\frac{R_c}{\rho_o}\cdot 10^2$ | 0.06 | 0.3 |
| $\frac{X_c}{\rho_o}\cdot 10^2$ | 6.9 | 5.0 |

**Table 11.**Characteristic wave impedances of aerial curtain made of uncoated wire EI708A with nickel coating at frequency f =3 GHz

| | Calculation | Experiment |
|---|---|---|
| $\frac{R_c}{\rho_o}\cdot 10^2$ | 0.12 | 0.6 |
| $\frac{X_c}{\rho_o}\cdot 10^2$ | 7.0 | 5.0 |

## DISCUSSION

Results, obtained during laboratory studies of optical and radiophysical properties of new materials for use in large-sized reconfigurable spacecraft antenna reflectors of, make this work unique, as well as timely, taking into account that products for these laboratory studies are a part of large-sized reconfigurable reflector. Timeliness of space reflectors topics is determined by rapid development of radio astronomy, solar energy, space communication and investigations of the earth's surface and other planets from space, where placing into orbit and exploitation in space of large structures made of composite materials of different type and designation is required, some of which are large-sized reconfigurable antenna reflectors of rod guy-roped type.

## CONCLUSION

During laboratory studies of optical and radiophysical properties of new materials for use in large-sized reconfigurable spacecraft antenna reflectors the next results were obtained:

- Spectral optical properties of carbon composites based on epoxy binder and 3 types of different fibers
- Spectral optical properties of metal tips for 2 types of different alloys
- Permeability of aerial curtains of radio engineering application made of different materials
- Reflectivity of aerial curtains of radio engineering application made of different materials
- Spectral optical characteristics of aerial curtains of radio engineering application made of different materials
- Frequency dependence of reflectivity of aerial curtains of radio engineering application.

As it follows from results of measurements in frequency range from 2 to 20 GHz, reflectivity of carbon fiber is equivalent to metal surface. At frequencies from 20 to 43.5 GHz reduction of level of reflected power is registered in 2-3 dB, which corresponds to losses from 37% to 50%. Since the main load-bearing elements of reflector are placed behind metal aerial curtain forming aerial reflecting surface, their influence on angular pattern is negligible. Consideration of radiophysical characteristics may be necessary in the case of placement of radiator struts above concave surface of reflector.

The results of research provide evidence of high reflectivity of metal aerial curtains in wavelength range *L* of 2 GHz, typical for space communication systems with large-sized reconfigurable antenna reflectors.

## ACKNOWLEDGEMENTS

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