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USING CARBON-BASED COMPOSITE MATERIALS FOR MANUFACTURING C-RANGE ANTENNA DEVICES

N. Dugin[1,2], T. Zaboronkova[2,3], E. Myasnikov[4]

[1] Radiophysical Research Institute, 25/12a B. Pecherskaya Str., Nizhny Novgorod 603950, RUSSIA

ndugin@yandex.ru

[2] University of Nizhny Novgorod, 23 Gagarin Ave.,
Nizhny Novgorod 603950, RUSSIA

[3] R.E. Alekseev Technical University of Nizhny Novgorod, 24 Minina Str., Nizhny Novgorod 603950, RUSSIA

[4] Volga State University of Water Transport, 5a Nesterova Str., Nizhny Novgorod 603950, RUSSIA

C-range horn antenna made of a graphene-containing carbon-based composite material has been developed. Electrodynamic characteristics of the developed antenna and the identical metal antenna have been measured in the frequency range of 4.6–4.9 GHz. We have created two prototypes of horn antennas made of (i) carbon fiber and (ii) carbon fabric. It has been shown that the horn antenna made of graphene-containing composite material is capable of efficiently operating in the C-range frequency and possesses almost the same electrodynamic characteristics as the conventional metal antenna of the same geometry and size. However, the carbon-based antenna has enhanced stability in the wide range of temperatures to compare with the corresponding metal antenna.

Keywords: *composite materials, C-range frequency, electrodynamic antenna characteristics, graphene-containing carbon, horn antenna.*

1. INTRODUCTION

It is well known that carbon-based materials are widely used in aerospace and shipbuilding industry, and are considered promising in the future for antenna techniques. In the past decade, composite materials were mainly used for manufacturing the structural elements of microwave devices, which require improved durability. When using carbon materials for reflector antennas, the surface of antennas is covered by a materials containing metal particle for providing the electric conduction, which makes the antenna characteristics similar to those of the conventional metal prototypes. The use of composite dielectric metamaterials as elements of the waveguide or antenna systems (such as inserts, corrugated structures, coatings, etc.) can improve their reflection and scattering properties [1]–[3].

Despite a wide use of metamaterials in antenna techniques [3], little is known about the characteristics of microwave horn antenna made of carbon-based composite materials. Our studies have shown the possibility of using composite materials not only for manufacturing the elements of microwave devices, but also for creating antenna systems. We have already developed the prototypes of circular waveguide and horn antennas in microwave L-range (1.4–1.7 GHz) and shown that microwave antenna devices made of a graphene-containing carbon based material have almost the same characteristics as their metal analogues [4], [5]. In the present research we have created two prototypes of C-range horn antennas made of (i) carbon fiber and (ii) carbon fabric.

2. FORMULATION OF THE PROBLEM

It is the purpose of the present research to develop C-range horn antenna made of a graphene-containing carbon-based composite material. The devices based on carbon composite materials have a long lifetime, enhanced immunity to corrosion, the record-breaking durability-to-weight ratios, and high stability in a wide range of temperatures (see, e.g., [4], [6] and references therein). Note that the graphene-containing material properties depend on the concentration of a binding substance in the composite material [4], [7].

At first, we measured the conductivity of a carbon composite material containing graphene structures in the centimeter-wave range. The conductivity of such a material reached a value of 10^5 S/m [7]. As it is known, typical conductivity values for metals lie in the limits of 10^3–10^6 S/m. We also studied the polarization properties of the graphene-containing carbon composite material in the microwave range as a function of the concentration of the graphene structures. It was found that in the case of rotation of the composite-material thin plate by 90^0, the polarization coefficient with respect to the field amplitude amounted to about 20–30 %, depending on the concentration of a binding substance in the composite material [8]. Note, that the anisotropic properties of the composite materials may influence the radiation of electromagnetic waves from the carbon-based horn antenna, including such important characteristics as the radiation pattern, the antenna gain, etc.

To manufacture the prototype of C-range horn antennas made of carbon composite material, we used carbon fiber or carbon fabric and epoxy resin modified by graphene structures as a binding substance. It should be noted that we created two prototypes of horn antennas made of (i) carbon fiber and (ii) carbon fabric. The electrodynamic characteristics of both antennas were measured at a frequency of 5 GHz and compared with those of a conventional metal antenna of the same geometry and size.

It was shown theoretically and confirmed experimentally that for the waveguide of circular cross section made of a composite material with anisotropic property, the more efficient excitation of the H_{11} wave (or the H_{10} wave in a rectangular waveguide [9]) took place if the carbon fibers in the composite material of the waveguide walls lied in the plane perpendicular to the waveguide axis [4]. For the theoretical calculation of the composite antenna parameters, we used the model of a circular cross section waveguide with finite thickness of a wall. The waveguide is immersed in a free space. It was assumed that the coductivity of the medium inside walls of the waveguide was described by a dielectric tensor with zero off-diagonal elements. Satisfying the continuity conditions for the tangential components on the boundaries of the waveguide walls we arrived at the equation for the eigenvalues of the waveguide. This equation allows us to estimate the geometrical parameters of the waveguide segment of C-range horn antenna. We obtained that the type of the fiber winding (longitudinal or transverse) was determined by the polarization of the antenna-excited electromagnetic field in the case of anisotropic conductivity of the walls. Further, we discuss some details of the manufacturing of horn antennas.

3. MANUFACTURING OF C-RANGE HORN ANTENNA

The horn antenna prototype contained the sequentially connected horn and segment of a circular waveguide, which were made of a graphene-containing composite material. During the manufacturing of the composite-material-based antennas, we used Zoltek Panex 35 (50K) carbon fiber (for the first prototype) and carbon fabric (for the second prototype) and the resin as binding substance, which was modified by graphene powder. The carbon fabric is a plain-weave of indicated carbon fiber. The structure of the carbon fiber and carbon fabric is shown in Fig.1. The size of unit cell of fabric is equal to $1.5 cm \times 1.5$ cm. The conductivity of graphene-containing composite material depends on the binding substance. Note that the conductivity of composite material used for manufactoring of C-antenna is almost isotropic.

To manufacture the antenna, firstly we made blank matrix. The blank matrix was made from duralumin and had the external sizes exactly coinciding with the calculated geometric parameters of the device. Then we applied the required number of layers of the graphene-containing carbon fiber (or carbon fabric) to the external part of the blank using the transverse winding (Fig. 2). The thickness of the waveguide walls was determined by the necessary strength of the construction and approximately was equal to 3–5 mm. The blank matrix was separated from specimen after solidification of the antenna walls. The surface roughness of C-range antenna was less than $10^{-2}\lambda$. Thereafter removal of surface roughness of the antenna may be reached by the vacuum shaping. It is also worth noting that the process of manufacture of C-antenna is the same as L-antenna described in detail in [4], [5].

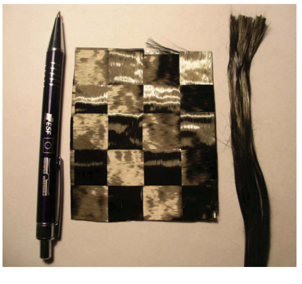


Fig. 1. Structure of the carbon fabric and the carbon fiber.

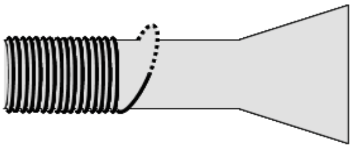


Fig. 2. Transverse winding of the carbon fiber to internal blank matrix.

As a result, we had the antenna prototypes made of the composite material. As an excitation device for the carbon-based antennas we used the analogous element of the metal antenna. Two orthogonal dipoles were used as excitation elements (Fig. 3).

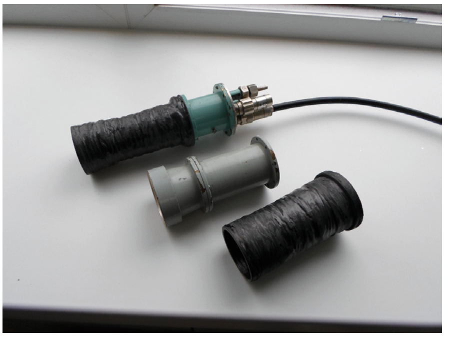


Fig. 3. Excitation elements.

Fig. 4. View of the antennas made of metal (left), carbon fiber and carbon fabric (right, respectively).

The antennas made of carbon fiber and carbon fabric are shown on the right-hand side of Fig. 4, respectively. The geometry and structural features of the antenna prototypes were entirely identical to those of the metal antenna used for comparison with the carbon-based prototypes. The metal antenna is shown on the left-hand side of Fig. 4. As a result, the main characteristics of the manufactured antenna turned out to be almost identical to those of the metal antenna. Note that the creation of C-range antenna made of the graphene-containing carbon composite material and the study of its electrodynamic characteristics had been performed for the first time.

4. ELECTRODYNAMIC CHARACTERISTIC OF C-RANGE HORN ANTENNAS

The following electromagnetic parameters of the carbon-based antenna prototypes and metal antenna were measured: (i) the standing-wave ratio (Fig. 5), (ii) the amplitude-frequency response (Fig. 6) and (iii) the radiation pattern (Fig. 7). The measurements were performed by standard methods [10] under laboratory conditions without using an anechoic chamber. Receiving and transmitting antennas were located in the far zone relative to each other.

Figure 5 shows the standing-wave ratio (SWR) in the frequency range of 4.5–5.4 GHz for the antennas made of metal (5a, solid line and 5c), carbon fabric (5b, point line) and carbon fiber (5a, point line and 5d). It is seen in Fig. 5b that there is no essential difference between the corresponding measured values for the antennas made of carbon fiber and carbon fabric. It is seen in Fig. 5a that the dependences of SWR for carbon-based antennas are more smoothed than that of the metal antenna. It should be noted that the maximum (1.5) and minimum (1.2) values of the standing-wave ratio are approximately the same for all types of antennas.

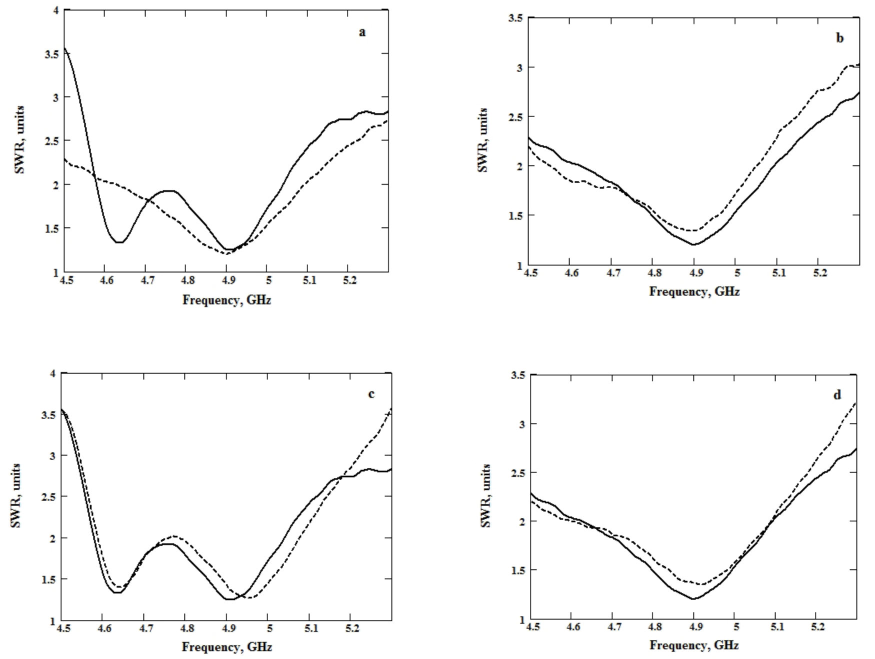


Fig. 5. The standing-wave ratio as a function of frequency for the antennas: a) made of the metal (solid line) and carbon fiber (point line) for the vertical field polarization; b) made of carbon fiber (solid line) and carbon fabric (point line) for the vertical field polarization, c) made of metal for the vertical (solid line) and the horizontal (point line) field polarizations, d) made of carbon fiber for the vertical (solid line) and the horizontal (point line) field polarizations.

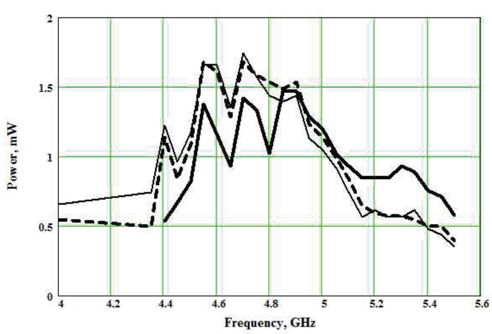
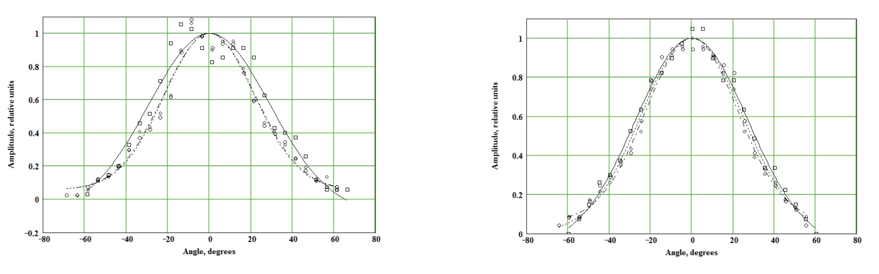


Fig. 6. The power of output signal as a function of frequency for the metal antenna (solid line), carbon fiber antenna (dashed line) and carbon fabric antenna (thin line).

The main antenna parameter is the gain, which characterizes the antenna efficiency, i.e., ohmic and radiation losses. The relative change of the antenna gains was measured by means of the amplitude-frequency response. Figure 6 shows the dependence of the power of the antenna output signal as a function of frequency for the metal antenna (solid line), carbon fiber antenna (dashed line) and carbon fabric antenna (thin line). It is seen that qualitative coincidence of all curves takes place. The sharp variations of curves in Fig. 6 are stipulated by peculiarities of excitation devices and transmission antenna characteristics. The operating frequency of antennas may be determined as the range of 4.6–4.9 GHz.

The radiation pattern of antennas was measured at frequencies of 4.75 GHz and 5 GHz. Figure 7 illustrates the radiation patterns (main lobe) of the metal (dashed line) and carbon-based antennas (solid line) for the vertical polarization at a frequency of 4.75 GHz (Fig. 7a) and at a frequency of 5 GHz (Fig. 7b). For convenience, the measurement results for the main lobe of the radiation pattern of each antenna (circles or squares) were approximated by a Gaussian function (dashed or solid line).

It is seen in Fig. 7 that the difference between the corresponding measured values does not exceed 5 %, which is quite satisfactory for the laboratory tests. The main lobes of the radiation pattern of carbon fiber antenna and carbon fabric antenna practically coincide. Good agreement of all the measured quantities for the three antennas was observed. However, the distortion of radiation pattern (circles or squares) at a frequency of 4.75 GHz is more essential than at a frequency of 5 GHz. It was caused by conditions of laboratory measurements.



a) b)

Fig. 7. Radiation patterns of the metal antenna (dashed line) and carbon-based antenna (solid line): a) at a frequency of 4.75 GHz; b) at a frequency of 5 GHz. Circles (squares) correspond to the radiation patterns of the carbon-based antenna (metal antenna) without Gaussian approximation.

5. CONCLUSION

It has been shown that the C-range horn antennas made of carbon-based composite materials modified by the graphene structures are capable of efficiency operating and have almost the same characteristics as their metal analogue. We hope that in the future after improving the technology of the antenna manufacturing, the graphene-containing composite antenna devices will have substantial advantages over the metal analogues in terms of some key parameters (weight, temperature stability, durability, immunity to corrosion, etc.) and will be able to replace the conventional metal antennas.

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OGLEKĻA KOMPOZĪTMATERIĀLU IZMANTOŠANA C JOSLAS ANTENU IZGATAVOŠANAI

N. Dugins, T. Zaboronkova, E. Mjasņikovs

K o p s a v i l k u m s

C diapazona rupora antenas tika izgatavotas no grafēnu saturošiem oglekļa kompozītmateriāliem. Tika mērīti šo antenu un analogas metāla antenas elektrodinamiskie raksturlielumi 4,6 – 4,9 GHz frekvenču diapazonā. Mēs izgatavojām divus rupora antenu prototipus: a) uz oglekļa šķiedru bāzes, b) uz oglekļa šķiedru auduma bāzes. Parādīts, ka grafēnu saturoša kompozītmateriāla rupora antena var efektīvi darboties C diapazona frekvencēs, un tās elektrodinamiskie raksturlielumi ir gandrīz vienādi ar tādas pašas ģeometrijas un izmēru metāla antenas raksturlielumiem, bet oglekļa kompozītmateriālu antena ir stabilāka par atbilstošu metāla antenu plašā temperatūru diapazonā.

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