Experimental determination of the influence of the radome on the characteristics of the radio-technical system

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Abstract. This article proposes a methodology and considers the results of experimental studies of the influence of the antenna radome on the characteristics of the radio system installed under it. To study the influence, a technique was developed and tested to determine the level of signal attenuation in the radome wall during thermal heating. A detailed description of the methodology for measuring the level of signal attenuation in the radome wall is given. For research, a special stand has been created that allows measurements of the level of signal attenuation in the radome wall when it is heated. Measurements were made of the level of signal attenuation in the radome wall during heating in accordance with a given temperature dependence on exposure time. Based on the analysis of the results obtained, it was found that an increase in the level of signal attenuation can lead to a deterioration in the radio characteristics of the microwave system «antenna- radome» and the radio system as a whole.

1. Introduction

The dielectric materials intended for the manufacture of radome for aircraft should have special properties, which is associated with the need for the radome to work under conditions of heating with an oncoming aerodynamic flow (figure 1).

The radome must withstand particularly high thermal and mechanical loads as part of high-speed aircraft. The radome performs two main functions: it must provide effective thermomechanical protection of the aircraft equipment at high temperatures and pressure created by the oncoming unsteady air flow in flight, and on the other hand, it must maintain the specified radio characteristics of the radome, providing high-precision measurements of the kinematic characteristics of the target by the airborne radar, in particular angular measurements, in various modes and flight conditions of the aircraft.

Operating experience and numerous theoretical and experimental studies have shown that radomes made of even the best dielectric materials with high accuracy noticeably change the radiation characteristics of the antennas they protect [1].

Radomes of large elongation, usually installed on high-speed aircraft, noticeably worsen (radio transparency decreases, angular measurement errors increase) if the radome is unevenly heated by the oncoming aerodynamic flow [2]. The magnitude and laws of temperature changes on the side surface of the radome as a result of aerodynamic heating depend on a number of physical factors: speed and altitude, thermophysical properties of the material, compartment design, configuration of the radome, etc.
Depending on the design of the radome and operating conditions, a significant temperature gradient arises: along the generatrix of the radome (figure 2). Even for a constant speed of high-speed flight, the surface temperature along the generatrix of the pointed radome will be different. During thermal heating, the temperature appears to be maximum at the surface near the tip of the pointed radome and minimum at its base.

In [3], a numerical simulation of aerodynamic flow around a high-speed flight of an aircraft for different angles of attack is presented. An analysis of the simulation results shows that when the angle of attack changes, pressure and temperature are redistributed on the radome surface.
Thermoradiotechnical tests, which must be carried out both in the cold state of the radome, after heat heating and in the process of its thermal heating, in order to establish the dependences of changes in the radio technical characteristics of the radome on external influences, are of great importance for ensuring high radio technical characteristics of the radome.

Currently, measurements of radio characteristics under normal conditions based on anechoic chambers are not difficult. However, there is a need to create techniques for predicting dynamic changes in the parameters of radomes, which correlate well with experimental results during thermal heating of the radome. External influences (especially with regard to temperature effects) can significantly change the parameters of dielectrics.

The main methods for measuring dielectric parameters during thermal heating are [4]:

- resonance method;
- waveguide method;
- optical method;
- free space method, etc.

Each of the above methods for measuring physical parameters has its own characteristics. So it should be noted that optical methods solve the problem of measuring the physical parameters of dielectrics in the millimeter frequency range using interferometers and open resonators.

It should be emphasized that all waveguide and resonance methods, except for the restrictions determined by the limiting temperatures, do not allow measurements to be made during dynamic heating of the dielectric, as well as when its state changes. As shown, the waveguide and resonator methods are suitable only for statistical investigation of the temperature dependences $\varepsilon(T)$ and $\tan \delta(T)$. However, they are the main methods for measuring physical parameters in the decimeter and centimeter frequency ranges.

The greatest successes in measuring the parameters of dielectric materials with a change in their physical state associated with high-temperature heating were achieved in [5]. In this paper, the physical and technical properties and technological features of obtaining a number of materials of radiolucent ceramic radome are considered. The main frequency dependences of the materials of dielectric parameters under the influence of thermal heating are revealed.

The dynamic measurements of the radio characteristics of aircraft radome have been the subject of several works. So in [6] a method for measuring the radio technical characteristics of a radome is presented.

To implement this method of measuring the radio characteristics of radome, a special stand has been created that ensures the following actions. The bottom line is the sequence of heating and measurements. A radome with an antenna system mounted on a slewing ring is first heated by infrared emitters to a certain temperature. After heating, the slewing ring is rotated 180° and carry out the measurement of radio characteristics.

Another method for measuring the radio technical characteristics of radome is the method proposed in [7]. The essence of the method lies in the fact that the temperature field on the outer surface of the radome is created by focusing on the surface using parabolic reflectors of radiation from individual linear infrared emitters, which are located along the focal lines of the reflectors. Emitters with reflectors are located along and around the axis of the radome at such a distance that its ratio to the radius of the radome is more than ten. A receiving antenna is installed inside the radome, and a transmitting antenna on the outside from the nose of the radome, or vice versa.

The mentioned methods, in fact, cannot always give accurate information about the dynamic dependence of the change in radio technical characteristics, taking into account the peculiarities of uneven heating of the entire surface of the radome. Another reason for using these methods is related to their technical implementation. In the first case, in the conditions of measurements it is impossible to talk about the continuous and accurate determination of the radio technical characteristics during heating, since the test object has time to cool down during the dilution of the heaters, which is a necessary procedure for this method. In the second case, zonal heating does not always ensure heating of the radome surface as in real aerodynamic heating.
To conduct accurate dynamic reference to the gradient of temperature measurement on the surface of the radome, a method is proposed for measuring the radio technical characteristics of the radome during heating.

The purpose of these studies is to test experimental studies of the influence of the antenna fairing on the characteristics of the radio system installed under it.

The novelty of this work, in a similar context, is experimental radio technical research under conditions as close as possible to aerodynamic heating. Conducting experimental radio engineering research is complex and expensive in terms of technical implementation. Therefore, most similar studies have theoretical results [8-10].

2. The method of measuring the level of attenuation of the signal in the wall of the radome during heating
This method allows measurements of the radio technical characteristics of the radome during heating, as close as possible to real heating during flight. A general view of the installation for carrying out measurements is presented in Figure 3. Heating is carried out using infrared emitters (heaters) [11]. With this heating method, infrared heaters are usually located at a close distance from the test object. Therefore, it is necessary to take into account their presence when conducting measurements of radio technical characteristics. The functional diagram of the installation with the main blocks is shown in figure 3.

For heating, heating panels with quartz tube lamps with bent ends are used. Reflected polished aluminum panel screens are water cooled. Lamps with the aim of cooling a quartz bulb in forced mode are blown with air. For this, a collector for blowing lamps is installed on each heating panel. The heating panels are attached to the sliding frame. The panels are arranged in three rows of eight panels in a row, forming, when the frame is closed, three rings around the radome (figure 4). The radome is heated in 6 independent control zones (bottom, top, side, bow, middle and aft) according to the appropriate temperature regime.
Figure 4. Location of heating panels around the radome.

To measure temperature and control the heating mode, thermocouples are installed on the radome opposite each heating panel (figure 5). This arrangement of heating elements and measuring thermocouples allows you to precisely control the heating course and temperature in all sections of the radome. The experiment accepted the condition that thermocouples do not affect the measurement results, since the thickness of thermocouples is much less than the wavelength $\lambda$.

Measurement, processing and recording of the readings of all temperature sensors and control of the heaters is carried out by the heating control and management system.

Figure 5. Location of thermocouples on the radome.

According to the methodology being created, the test object is a prototype of the radome, which will be subjected to thermal heating.
Dynamics of temperature change is chosen arbitrarily. In this case, during testing, the temperature gradually increases on the surface of the radome to $T_{\text{max}}$ ($^\circ$ C). A typical temperature dependence on exposure time is shown in figure 6.

![Figure 6. Temperature change during heating.](image)

3. Measurement of the signal attenuation level in the radome wall during heating
   The main purpose of the tests is to measure the level of attenuation of the signal in the radome during its aerodynamic heating.
   
   Signal attenuation in the radome under normal climatic conditions is compensated and reduced to zero dB.
   
   Measurements of the radio transparency coefficient are relative. Therefore, the tests are carried out sequentially in 3 stages in the following sequence:
   
   - measurement of the attenuation level of the signal without radome (calibration);
   - measurement of the level of attenuation of the signal in the radome under normal conditions;
   - measuring the level of attenuation of the signal in the radome during heating according to the dynamics of temperature changes on the surface of the radome as in Figure 6.

   The measurements are performed by the free space method [12], when the change in the signal power level after passing through the radome wall is controlled. The measurement results were recorded using a vector network analyzer.

4. Results and discussion
   According to the results of the tests, the dependence of the signal attenuation level in the radome during heating was obtained, according to the dynamics of temperature changes on the radome surface. The dependence is shown in figure 7.
   
   According to the results of the analysis, it was found that in the maximum heating temperature the highest value of the signal attenuation level in the radome wall was noted. Analyzing the obtained experimental results, a conclusion follows about the influence of thermal heating of the radome on the characteristics of the radio engineering system installed under the radome.
   
   An increase in temperature led to a change in the level of signal attenuation in the radome wall. A probable reason for the increase in the attenuation level is a change in the dielectric parameters of the material [13]. Thus, a change in the dielectric constant of the material of the radome wall leads to a shift in the working frequency of the radome, and an increase in the level of attenuation of the signal indicates
an increase in active losses in the radome, which are directly proportional to the tangent of the angle of dielectric losses.

![Figure 7](image)

Figure 7. The dependence of the level of attenuation of the signal in the radome during heating.

It should also be noted that the process of heating the radome led to irreversible changes inside the wall of the radome that the radio technical characteristics measured after cooling do not coincide with the characteristics before heating. A possible reason for such changes is a partial or complete burnout of the binder in the material of the radome wall. Burnout of the binder may have led to a decrease in the dielectric loss tangent, which led to a decrease in the signal attenuation level at the final heating stage.

The methods proposed in the international literature cannot always give accurate information about the dynamic dependence of changes in radio technical characteristics, taking into account the peculiarities of uneven heating of the entire surface of the fairing due to the complexity of their technical implementation. The main reason is the complicated technical implementation of continuous and accurate reproduction of aerodynamic heating.

5. Conclusion

The above quantitative estimates for calculating the temperature changes in the radio characteristics of a radome undergoing thermal heating show a significant temperature deviation of the properties of the used dielectrics and, as a result, often unacceptable deterioration of the radio characteristics of the microwave system “antenna-radome” and the radio system as a whole. All of the above fully applies to antenna windows (radomes) and dielectric sealing inserts of any configuration and size, operating in powerful microwave paths.

The study of dielectrics in various temperature conditions allows us to proceed with the prediction of operational parameters and characteristics of radomes made of these materials.

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