THE ERROR IN DETERMINING THE TEMPERATURE OF PLASMA ELECTRONS

Abstract. The error in determining the temperature of plasma formation electrons surrounding the spacecraft on the descent trajectory using the radiometric diagnostic method is considered. It is noted that the error depends on the type of radiometer and the matching of the onboard antenna of the radiometer. The error is analyzed and its quantitative assessment is given.

Keywords; atmospheric entry, plasma, radiometric diagnostics, electron temperature, error

Introduction: Spacecraft on the descent trajectory in the Earth's atmosphere are exposed to air plasma formation [1]. The effect of plasma on radio communications on the spacecraft-Earth route leads to a disruption of radio communications [2-4]. To develop methods to combat the loss of radio communication, it is necessary to know the electrical characteristics of plasma for flight conditions in the atmosphere. Many well-known methods for diagnosing plasma parameters cannot be used for field measurements. Of all the currently existing methods for diagnosing on-board plasma, only two are ~~hardware implemented~~hardware-implemented and practically used - radiometric and probe.

Method: Radiometric diagnostics became widely used with the development of highly sensitive radiometers [5]. The method of radiometric diagnostics consists ~~in~~ ofmeasuring the radio brightness of plasma radiation using an ~~on-board~~onboard antenna and a radiometric receiver [6].From the point of view of analyzing the loss of radio communication on the descent trajectory, the reflection zone, which occurs for an operating frequency lower than the plasma frequency, is of the greatest interest. For this zone, the diagnostic results are determined only by the plasma parameters at the boundary. In this case, it is possible to determine the radio brightness temperature at the operating frequency of the on-board radio equipment, and through it the temperature of the electrons.

The electron temperature is one of the most important characteristics of a plasma~~,~~ since its value determines the concentration of electrons and other electrical characteristics of the plasma, such as, for example, the absolute permittivity and electrical conductivity of the plasma and the plasma frequency, which determine the passage of electromagnetic waves through the plasma.

When determining the temperature of electrons in the reflection zone of the plasma section from the measured value of the radio brightness plasma temperature with a radiometer, the RMS relative error in determining the electron plasma temperature is written as [7]

$$\delta T_e = \sqrt{\delta^2 T_b + \delta^2 T_R}, \qquad (1)$$

Comment [BG1]: Complete the proposal according to background, objective, methods, results, and conclusion format. It seems incomplete.

Comment [BG2]: Revise this statement where $\delta^2 T_b$, $\delta^2 T_R$-is the RMS relative error in determining the radiometer of the radio brightness plasma temperature, and the RMS relative error in determining the temperature by the radiometer due to misalignment of its input path, (values of the reflection coefficient), respectively.

$$\delta_R = \sqrt{\delta_T^2 + \delta_c^2}, \qquad (2)$$

where $\delta_T{}^2$ is the RMS relative error of the recording equipment, δ_c ~~is~~ Isthe RMS relative error of the radiometer calibration.

In [8], the causes of its occurrence δ_b^2 ~~are~~ Areanalyzed in detail and numerical values of its magnitude are given.

For a radiometer with frequency and time separation, the error in determining the temperature of electrons can be represented as

$$\delta T_e = \frac{\sqrt{\delta^2 T_a + \delta^2 R (T_n - T_e)/T_a + R^2 \delta^2 T_n}}{1 - R^2}, \qquad (3)$$

where δ_a^2 ~~is~~Is.~~the~~ TheRMS relative error in determining the temperature of the radiometer antenna, T_n is the noise temperature of the radiometer

For a radiometer with feedback in the input circuit

$$\delta^2 T_e = \sqrt{\delta^2 T_n + \delta^2 T_я (1/L^2 K^2)}, \qquad (4)$$

where L is the decoupling value of the power divider of the radiometer input circuit, and K is the transmission coefficient of the input path, taking into account feedback.

Here the value is written as

$$\delta T_n = \frac{R^2}{[n - R^2(n-1)]}, \qquad (5)$$

where n is the power division coefficient.

The expression for K can be represented as

$$\delta T_n = \frac{1 - R^2}{[n - R^2(n-1)]}. \qquad (6)$$

Result: Figure 1 shows the dependence of the RMS relative error in determining T_e ~~as~~ Asa function of the energy reflection coefficient, calculated using the expressions (1)-(6).

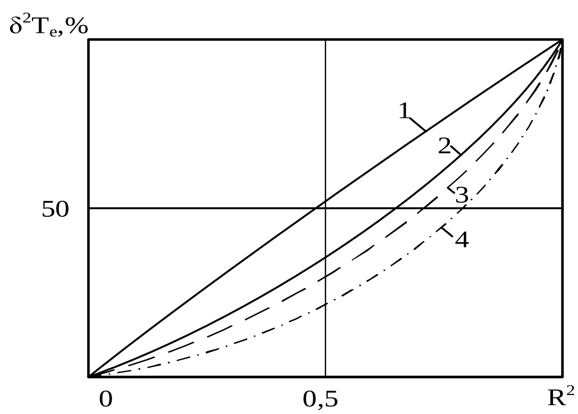

Figure 1- The RMS relative error of determining T_e from R^2, 1- n=1; 2 -n=2; 3- n=3.16; 4- n=10

As can be seen from Figure 1, for reflection coefficients R^2 <0.5, the error in determining the electron temperature of the plasma will be determined mainly by the value δ_a^2. For large values R^2 (more than 0.8), the error in determining T_e ~~does~~ Doesnot exceed 30%, while when using a modulation radiometer, the RMS relative error in determining the electron temperature of the plasma will be 80%.

Figure 2 shows the RMS relative error in determining the electron temperature of the plasma as a function of the power division coefficient. It can be seen from the figure that the optimal value of the division coefficient is approximately 6.

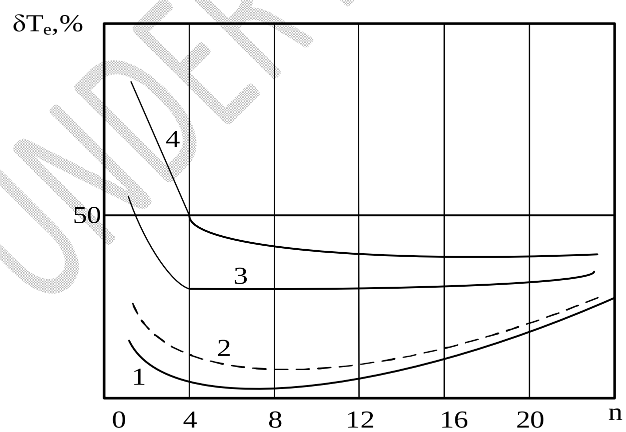

Figure 2 - Dependence of the RMS relative error in determining the electron temperature of the plasma on the power division coefficient

1- R^2 =0,1; 2- R^2 =0,2; 3- R^2 =0,6; 4- R^2 =0,8

Conclusion: The results obtained show that it is possible to determine the temperature of plasma electrons with acceptable accuracy using the radiofrequency value of the radiofrequency plasma temperature measured by the radiofrequency method. Preference over modulation radiometers should be given to radiometers with feedback in the input circuit.

REFERENCES

1. Martin J.Re-entry into the atmosphere. M.: Mir. 320 p.
2. Abanti Nag, Rayasa Rao, Prasanta Panda High temperature ceramic radomes (HTCR) – A review. Ceramics International, 2021. doi: 47. 10.1016/j.ceramint.2021.04.203.
3. Cease M and Savion L 2020 Applied radiation physics techniques for diagnostic evaluation of the plasma wind and thermal protection system critical parameters in aerospace re-entry. Progress in Aerospace Sciences 112
4. Jiannan Tu, Song Paul, Reinisch Bodo W. Plasma sheath structures around a radio frequency antenna. Journal of Geophysical Research, 113(A7), 2008. doi:10.1029/2008ja013097
5. Smirnov, M. T. Modeling of satellite microwave radio interferometric measurements for remote sensing of the Earth/ M. T. ~~Smirnov./~~Smirnov. // Modern problems of remote sensing of the Earth from space. Vol. 19, No.2. 2022. pp.23-31.
6. MikhailovV.F.,~~,~~ PobedonostsevK.A., BraginI.V. Forecasting the operational characteristics of antennas with thermal protection. St. Petersburg, Shipbuilding. 1994.300 p.

7. VasilyevaD.V., MikhailovV.F. Error in determining the radio brightness temperature of the plasma. International Forum “Metrological support of innovative technologies" St. Petersburg, GUAP. 03.04.2020, pp. 142-144.

8,Mikhailov ~~V.F..~~V.F.Bragin I.V.,BraginS.I. Satellite equipment for remote sensing of the Earth/. M.: University book.2008. 339 p.

Comment [BG3]: Mention the page number