DIRECT DETERMINATION OF IONOSPHERIC PLASMA STRUCTURAL PARAMETERS IN THE EXPERIMENT WITH A SPHERICAL ION TRAP

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INTRODUCTION

The study of the properties of Earth-surrounding plasma is of great practical importance. Plasma structural parameters are determined by the direct probe method. The results of these studies complete the physical analysis of Earth-surrounding space and are related with space energy resources.

THEORETICAL MODELS

At a thermal velocity of the ions significantly lower than the velocity of the satellite V_o (relative to the plasma), the mean energy of the ions of mass M_i that have reached the probe is $\frac{1}{2} M_i V_o^2$. By the change of the positive bias, conditions are created for reaching the probe by the ions with different energies (respectively masses) and a possibility for mass selection, thus providing to obtain data for the density and temperature of the different kinds of ions [1].

Figure 1a displays the dependence of the ion current on the voltage applied to a probe for definite types of ions. The data is taken from [1], a probe characteristic of ESRO-1 mass spectrometer: grid transparency 30%, for oxygen ions O^+ with temperature 1000 K. To determine ion temperature, the second derivative of the current-voltage characteristics is used, Fig. 1b.

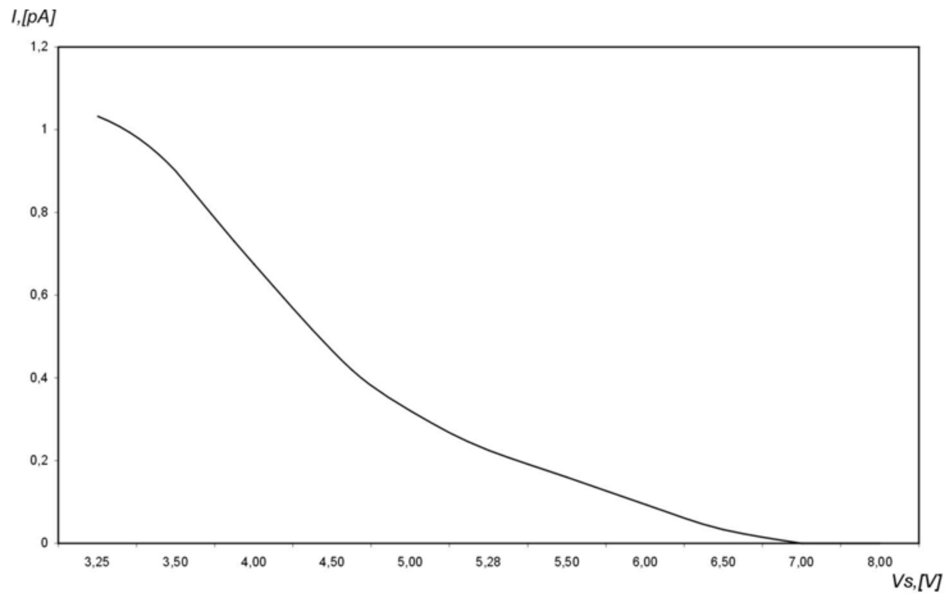


Fig. 1a

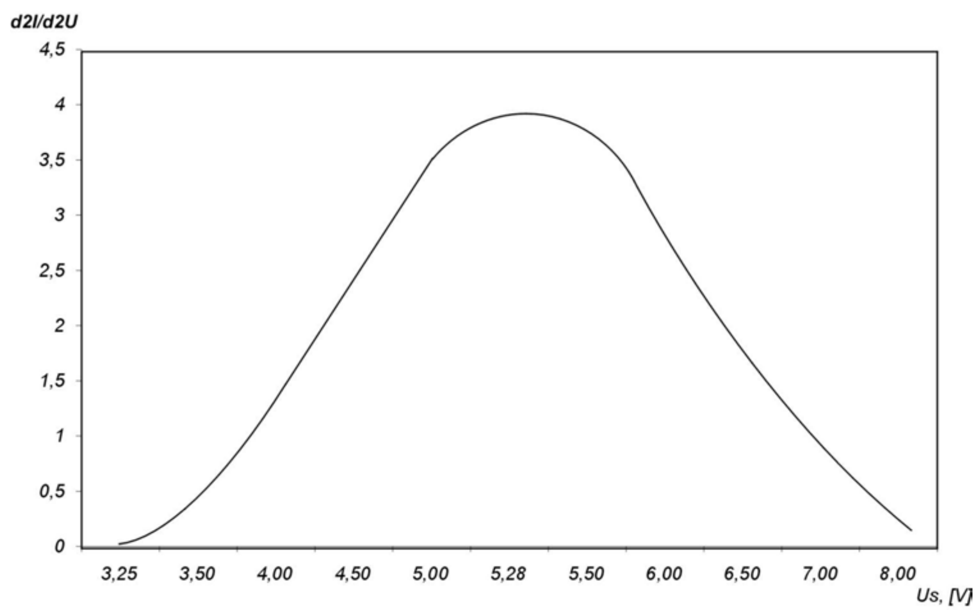


Fig. 1b

A spherical ion trap can be used as a measuring device that can determine the "mass number" of different types of positive ions at comparatively low mass resolution. In spite of this limitation, ion temperature can be determined, too [1]. Ion density is defined by the application of the result of Druyvestin (1930) who shows that the energy distribution of charge carriers collected by a probe biased to a voltage V relative to the plasma in the retarding region is given by

(1) $$\int(E)dE = \frac{1}{|U|^{1/2}} \frac{\partial^2 I}{\partial U^2} dU$$

(2) $$N_i = \int_0^\infty f(E)dE$$

The form of the function $\partial^2 I/\partial U^2$ for a spherical probe collecting current from plasma with drift velocity on which Maxwellian velocity distribution is superimposed has been studied by Medicus (1961, 1962) [2].

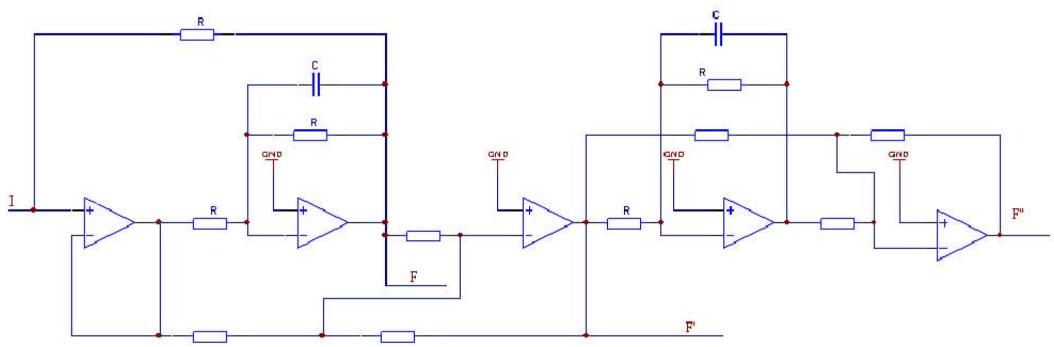
The analysis of the characteristics based on this theory is more convenient [1], [3]. The density N_i is obtained from the value of the second derivative function peak. The probe bias at which this maximum is obtained (detention bias) is used for the determination of M_i. The width of the second derivative function curve at level 0,5 is a “measure” of ion temperature T_i. On the basis of equations (1) and (2), the energy distribution E_i for ions of a given type can be also determined. The above-stated shows that, from the second derivative function of the probe current with respect to the voltage, almost all structural parameters of plasma ion components can be determined.

DEFINITION AND SOLUTION OF THE PROBLEM

The accuracy and the potentials of SIT experiment can be increased if on board of the satellite the current-voltage characteristics and their derivatives are obtained [3] as continuous real-time functions. From the second derivative of the characteristics, the plasma structural parameters N_i, M_i, T_i, E_i can be determined.

In the present work, we have suggested the solution of the problem for simultaneous obtaining of the current-voltage characteristics, its first and second derivatives as continuous real-time functions. This problem concerns the main amplifier in the circuit of a SIT probe experiment. This solution is a development of the authors’ idea that has been published in [4]. The derivatives of the input function can be calculated by a differentiating circuit. The main differentiating circuits are not used for direct computation of a function derivative because of the high noise level and the operation instability.

Operation stabilization and noise reduction can be attained indirectly when the derivative is calculated by the function and its integral [5]. This idea has been further developed in the present work by using minimum hardware and has been applied in two steps for obtaining the second derivative of the input function. The indirect approach for calculating a function derivative is a process approximation which works in the low frequency region [5], [4]. The type of the circuit that implements the described approach at a double step application (calculation of the first and second derivatives in a continuous form) is shown in Fig. 2.



The main amplifier contains high impedance input operation amplifier operating in the non-inverting mode and an inverting integrator with a feedback loop. At these stages, the input current SIT is converted into a voltage and the first derivative of the input function is calculated. During the next stages, a similar circuit of an integrator and amplifier that calculates the second derivative of the function is applied. The described circuit has been analyzed by operating methods to determine the frequency range in which the approximation conditions $f_{max}<<2_nRC$ are accomplished. Only the frequency determining elements are marked in the circuit. The obtained low-frequency range corresponds to the real experimental conditions.
The described circuit based on an indirect approach for calculation of the first and second derivatives of the input function as continuous real time functions has been experimented by means of a laboratory model. To simulate input functions, different in form (sinewave, triangular, orthogonal) voltage generators of amplitude of 0,35-3V have been used, at which stable operation has been observed.

CONCLUSION

The above described solution of the problem provides an opportunity for the immediate real-time obtaining of the first and second derivatives of the current-voltage characteristic as continuous functions by an approximation which operates in the low-frequency range. This makes it possible to determine directly the structural parameters N_i, M_i, T_i, E_i of the plasma in a SIT probe experiment decreasing useless information which, in its turn, simplifies the technique of measurement.

PERSPECTIVES

There are tendencies in the development of space technology for the next years to replace expensive space programs by smaller and cheaper programs that give faster results as well [6].
In many fields, intensive studies are carried out for the accomplishment and use of “distributed” systems of “micro-devices”. There are ideas to use “micro-satellites” as intelligent sensors for the simultaneous measurement at many points of ion concentration and temperature [6]. From this point of view, the suggested solution could be realized in a minimized version with a much lower power supply.

SUMMARY

The paper presents a solution for real-time immediate obtaining of the first and second derivatives of the current-voltage characteristics in a probe experiment with SIT which provides opportunity for direct determination of plasma structural parameters. An indirect approach has been used by which noise effect is reduced and operation is stabilized with minimized circuitry. Possible prospects for development of the measurement technique are outlined.

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